CHAPTER 3

WATER QUALITY

Lake Okeechobee water quality relates to both the watershed and in-lake processes. The SWIM Plan strategies focus on controlling nutrient inputs to the lake from the watershed and developing a predictive understanding how in-lake processes may affect the lake responds to changes in external inputs. The water quality goals have been established to protect and enhance the water quality of the lake and to meet regional environmental, potable water supply, and agricultural needs.

The following provides a summary of major challenges and strategies derived from the materials contained within this chapter.

Challenge: Phosphorus loading averages 136 tons above the SWIM Act target. Four key basins account for the majority of the phosphorus.

Strategy: Implement voluntary (landowner) initiatives to reduce flows and loadings, including isolated and riverine wetland restoration, dairy "hot spot" remediation, removing tributary phosphorus sediments, and research on improved pasture best management practices. Continue current WOD regulatory program, compliance monitoring, and modeling of potential load reduction scenarios.

Challenge: In-lake sediments contributing to nutrient and turbidity problems continue to be a major concern. Declining water quality at the south end of lake suggests that mud sediments may be increasing in spatial extent and data on sediment distribution and nutrient content are more than 10 years old.

Strategy: Conduct detailed mapping and nutrient assessment of sediments, determine the effects of lake stage on sediment resuspension, quantify in-lake nitrogen and phosphorus cycles, model responses to various load reduction scenarios, and develop linkages between the hydrodynamic and water quality models.

A. GOALS, OBJECTIVES AND STRATEGIES

Superscript notation indicates projects that are in the proposed budget (Chapter 9).

Goal 1: Reduce pollutant loads from the watershed to protect aquatic life and water quality in Lake Okeechobee.

Objective 1: Bring the over-target basins down to their phosphorus loading targets.

Strategy 1: Implement non-regulatory, landowner-based initiative for on-site retention of phosphorus and water.[1]

Strategy 2: Remove tributary sediments that are rich in phosphorus, and highly mobile.[2]

Strategy 3: Develop Best Management Practices for improved pasture, in particular, beef cattle agriculture as a nonpoint source of phosphorus, and continue modeling load reduction scenarios.[3,4,5,,6]

Strategy 4: Continue to implement the regulatory programs and monitoring.[7,8]

Objective 2: Achieve State Class I Water Quality Standards (Chapter 62-302, F.A.C.) within Lake Okeechobee, and Class III Water Quality Standards within the lake tributaries.

Strategy 1: Support the development and implement a comprehensive plan to address Class I/Class III water quality exceedances within Lake Okeechobee and its tributaries for the Lake Okeechobee Operating Permit.

Strategy 2: Assist local governments with storm water management systems to meet state water quality standards.

Strategy 3: Encourage the improvement and/or expansion of regional wastewater treatment facilities to meet state water quality standards.

Goal 2: Reduce in-lake nutrients, in order to attain a more natural (lower) frequency of potentially harmful algal blooms.

Objective 1: Quantify rates of internal nutrient loading from lake sediments so that accurate predictions can be made about the timing and extent of lake responses to potential management actions.

Strategy 1: Update data on location, mobility, and phosphorus content and efflux of lake sediments.[9,10]

Strategy 2: Continue the development and application of mathematical models such as Water Quality Analysis Simulation Package (WASP5) and hydrodynamic models to evaluate nutrient loading and assist in integrating information.[11,12]

Objective 2: Reduce uncertainty about in-lake sources, sinks, and cycling of nitrogen and phosphorus using research and modeling approaches.

Strategy 1: Perform in-lake and laboratory studies to measure aspects of the phosphorus cycle where there currently is a high level of uncertainty.[14]

Strategy 2: Perform in-lake and laboratory studies to measure major aspects of the nitrogen cycle.[18]

Objective 3: Quantify trends in limnetic and marsh zone water quality, and progress towards established lake enhancement goals.

Strategy 1: Incorporate water quality data into a comprehensive plan for assessing trends in long-term ecological data that may serve as measures of management activities and success.[28]

B. WATERSHED ISSUES-NUTRIENT CONTROL

The Lake Okeechobee watershed is dominated by agriculture, which contributes nutrients that have impacted the ecological condition of the lake. Phosphorus is of particular concern in this system because it has been identified as the key element that contributes to the eutrophication of the lake (Davis and Marshall 1975, Federico *et al.* 1981, Joyner 1972, Kissimmee-Okeechobee Basin Report 1972). A phosphorus load reduction goal was developed to restore the ecological condition of Lake Okeechobee. This goal requires a 40% reduction in phosphorus loading to the lake, based on the data collected from 1973-1979 (Federico *et al.* 1981).

Several programs have been implemented to achieve the phosphorus reduction in runoff from the watershed. These include:

- The Taylor Creek Headwaters Project and the TCNS Rural Clean Waters Program (RCWP). Under these programs, Best Management Practices (BMPs) were implemented that included fencing cows away from streams

- The Florida Department of Environmental Regulation's (FDER - now known as the Florida Department of Environmental Protection [FDEP]) Dairy Rule, which required construction of waste treatment systems for barn wastewater and runoff from high-intensity milk herd holding areas

- The Dairy Buy-Out Program, which provided an option for dairy farmers unable or unwilling to comply with the Dairy Rule

- A regulatory program implemented by the SFWMD, Works of the District which established a numeric phosphorus concentration limit for runoff from non-dairy land uses

Although these management programs for the Lake Okeechobee watershed have reduced the loading of phosphorus to the lake, only two-thirds of the 40% reduction have been achieved. The overall status of phosphorus loading to the lake is provided by the SFWMD Resource Assessment Division, which produce the "Water Quality Conditions Quarterly Report".

B1. Current Management Programs

Tributary phosphorus limitations were based upon reaching an in-lake phosphorus concentration of 40 µg/L (40 ppb) by July 1992 as recommended by a modification of the Vollenweider (1976) nutrient loading model, described in SFWMD Technical Publication 81-2 (Federico *et al.* 1981). The 1989 Interim Lake Okeechobee SWIM Plan (SFWMD 1989) set forth a recommended approach for meeting the phosphorus reduction goals of the 1987 SWIM legislation. According to the plan, all tributary inflows to the lake were required to meet the 0.18 mg/L (180 ppb) performance limitation for total phosphorus or maintain their 1989 discharge concentration, whichever was less. Basins that exceeded the 0.18 mg/L limitation were required to reduce their phosphorus concentrations and achieve compliance by July 1992. The plan identified priority basins that must meet the 0.18 mg/L limitation. The plan also recommended a regulatory program, the Works of the District (WOD) to achieve target phosphorus reduction goals based on land uses within the basins.

B1a. FDEP Dairy Rule Program

In June 1987, the FDEP enacted the Dairy Rule (Chapter 62-670, F.A.C.) which required that all dairy operations within the Lake Okeechobee watershed and its tributaries implement BMPs for the purpose of reducing phosphorus inputs into the lake. This is accomplished by the collection, storage, and land application of waste and nutrient-laden runoff from high-intensity use areas (HIAs), including milking barns, feed lots, holding pens, or contiguous milk herd pastures where the permanent vegetative cover is equal to or less than 80%. A total of 49 dairies, the majority located in the TCNS and Lower Kissimmee River (LKR) basins, came under jurisdiction of the rule.

The general concept behind the Dairy Rule was to achieve a nutrient balance by retaining phosphorus on-site for uptake by forage crops, followed by harvesting of hay or other crops for cow feed. Under the rule, each farm was required to develop a site-specific management plan providing for the collection, storage, and disposal of wastewater from HIAs during a 25-year, 24-hour storm event. Each plan required implementation of BMPs in accordance with guidelines from the USDA-Soil Conservation Service, now called Natural Resources Conservation Service (NRCS). These plans included detailed instructions for quantifying the nutrient balance, determining phosphorus production by cows, phosphorus uptake by plants, and construction of spray irrigation fields and storage ponds. All affected dairies were required to submit construction permit applications along with BMP designs to the FDEP by June 1989. Within 18 months of construction permit issuance, BMP construction was to be completed and an application for an operating permit submitted to the FDEP.

The SFWMD, in cooperation with the NRCS, provided assistance to the dairies in preparing construction plans by hiring two consulting firms in the summer of 1988. They prepared plans for 16 dairies, while a few chose to hire their own engineers. The FDACS also secured funds from the legislature to cost-share BMP construction within the Lake Okeechobee watershed. Best Management Practices implemented on the dairies generally included fencing cows away from watercourses; collection, storage, containment, and treatment of manure and wastewater runoff from HIAs; crop spray irrigation and land application of wastewater, solids, and sludge; as well as the establishment of buffer zones along natural watercourses and drinking water supplies.

The Dairy Rule did not establish a specific off-site water quality limitation, but outlined required BMPs for operation of each dairy that would provide reasonable assurances that each dairy could meet state water quality standards (FDEP Dairy Rule, Chapter 62-670, F.A.C.) and that acceptable phosphorus levels in off-farm discharges would be achieved (Albers *et al*. 1991). The Lake Okeechobee Technical Advisory Council (LOTAC) also reviewed the proposed FDEP Dairy Rule and concluded that properly constructed BMPs would most likely achieve the 1.2 mg/L limitation originally proposed by the SFWMD (LOTAC II 1990). Although the 1989 Interim Lake Okeechobee SWIM Plan established a target discharge limitation for dairies, the dairies were exempted from permitting and enforcement under the SWIM Plan since they were under the jurisdiction of the FDEP Dairy Rule.

Construction of BMPs was initiated in 1988 and was completed by December 1992 on 30 dairies with operating permits obtained from FDEP. All dairies that had achieved the 1.2 mg/L target received five-year permits, while all dairies that had not reduced discharge concentrations to the target received one-year permits. As a condition of permit renewal, FDEP requires the permittee to make modifications to the management plan which provide reasonable assurance that the dairy can achieve the target concentration.

Implementation of dairy BMPs have been completed at 30 dairies. Of the four dairies which closed after 1992, two dairies have since terminated their FDEP operating permits, one of which was purchased by the SFWMD with Save our Rivers funds in 1994. Currently, only 28 dairies have operating permits of which 26 are active at this time. Two dairies have temporarily closed while maintaining their Dairy Rule permits in an active status with the option of reopening at a later date. These closures have caused a further 3886 milk cow decline. The status of the dairies in the LKR and TCNS basins is shown in Table 3 and listed in Appendix C. Current and planned strategies for the Dairy Rule program are described in Section 4a.

Table 3. Dairy Rule and Dairy Buy-Out Program Status

FDEP Operating Permits	
26	Dairies with current operating permits and active
2	Dairies inactive with an operating permit
1	Dairy out of business
Dairy Buy-Out Program	
18	Dairies ceased operations under program
Save Our Rivers Program	
2	Dairies ceased operations under program

B1b. Dairy Buy-Out Program

The Dairy Buy-Out Program was established in 1989 upon request by the dairy industry, for farmers who were unwilling or unable to comply with the Dairy Rule by implementing BMPs. The Buy-Out applied a deed restriction to the property prohibiting future use as a commercial dairy or concentrated animal-feeding operation. The buy-out did not purchase the property or cows, but simply facilitated removal of the animals. Under this program, the state paid dairies approximately the same amount to stop milk production that would have been paid to construct BMPs on their land. The SFWMD paid approximately half of the cost of the program.

Of the 49 original dairies that existed in the LKR and TCNS basins before implementation of the FDEP Dairy Rule, 18 participated in the Dairy Buy-Out Program. A total of 14,039 milking cows were relocated under the buy-out program at a total State and SFWMD cost of $8,451,478. An undetermined number of replacement heifers and calves were removed as well. Of that total, SFWMD expenditures were $4,139,468. This program has been completed. Two additional dairies in the LKR Basin were closed under the SFWMD's Save Our Rivers Program resulting in the removal of 1,175 milking cows plus replacement calves and heifers.

B1c. Works of the District/Regulation of Non-Dairy Land Uses

As a result of the adoption of the 1989 Interim Lake Okeechobee SWIM Plan, Rule 40E-61, F.A.C. was developed by the SFWMD with an effective date of November 1989. The rule established criteria to ensure that use of, or connection to, a Works of the District (WOD) project or lands would be compatible with the SFWMD's ability to carry out the water quality objectives stated in Chapter 373.016 F.S.; Chapter 62-40 F.A.C.; and the SWIM Act as outlined in sections 373.451-373.4595 F.S. and Chapter 40E-61. This regulatory program applies to all non-dairy land uses and areas of dairies not covered by Rule 17-6.330 - 17-6.337 (FDEP Dairy Rule), discharging to WOD projects or lands located within the Lake Okeechobee drainage basin.

Works of the District projects include SFWMD-owned, operated, maintained, or regulated waterways, canals, water control structures, right-of-ways, wetlands, remnant oxbow or sloughs, lakes and streams which the SFWMD owns or has the responsibility of managing. All land uses within the basin are subject to the rule. However, the type of permit required depends on several factors: the type of land use, the extent to which it is a contributor of phosphorus to the lake, and the basin in which it is located. The deadlines for submittal of permit applications were prioritized to bring the most problematic basins into compliance first.

Individual permits were required for certain land uses in priority basins. All other basins required a General (Notice of Intent) Permit. In general, 10 land use types are impacted by the rule. Table 4 provides a simplified overview of the various land uses within the basin and the type of permit required by the SFWMD. In the basins north of the lake, the primary non-dairy land uses are improved pasture for beef cattle, and agricultural uses such as sod production.

Table 4. Works of the District Permits required for various land uses.

General Permit (Notice of Intent)	**Individual Permit**
● Urban Storm Water	● Dairies not covered by Rule
● Golf Courses	● Improved Pasture
● Sugar Cane	● Vegetable Farms/Row Crops
● Horse Farms	● Heifer Farms
● Nurseries	● Hog Farms
● Land Spreading of Sludge	● Poultry Farms
● Sod Farms	● Goat Farms

From January 1990 through May 1997, 695 permits have been issued in the LKR, S-154, S-191, S-71, S-72, S-127, S-135, S-4, L-59E, C-38D, S-133, S-65C, S-84, and Fisheating Creek basins. Of this total, 620 are individual permits and 75 are general permits. Permitting of all problematic parcels equal to or greater than 5 acres in size in all of the 14 priority basins is complete. Administrative maintenance of the permit files is an ongoing activity, as land use and ownership changes require permit modifications and transfers.

In the regulatory program, users of the WOD are required to meet specific off-site phosphorus concentration limitations. If the SFWMD monitoring data indicate that there is greater than a 50% probability that the average annual off-site discharge concentration will not be met, the affected land owner is required to take corrective measures to bring discharges from the property into compliance with the rule. The SFWMD conducts a two-pronged water quality monitoring program to identify phosphorus sites with high concentrations within the basin and to distinguish between landowners who are in compliance and those who are not. A routine biweekly water quality monitoring program is conducted on permitted parcels. At least one year of monitoring is required on all individual permits to document compliance status. A non-routine, specific-need surveillance monitoring program is also conducted throughout the basin to seek out unpermitted land uses and non-complying dischargers in both the priority and non-priority basins. Those parcels requiring corrective action have been identified. Current and planned strategies for the WOD program are described in Section 4b.

Everglades Agricultural Area Environmental Protection District

As an alternative to obtaining individual or general permits, the WOD Rule allowed landowners within the Everglades Agricultural Area Environmental Protection District (EAA-EPD) served by water management systems to submit an application for a collective permit known as a Management Plan Master Permit (also known as the EAA "Bubble" permit). This Master Permit encompasses approximately 240,000 acres of area that is tributary to Lake Okeechobee and that has authorized use of SFWMD works tributary to Lake Okeechobee. The overall goal was to reduce total phosphorus loads from the EAA-EPD by 8 tons/year by July 1992, and 10 tons/year by July 1994. The four adjacent storm water management districts and the state of Florida agricultural lease number 3420 (298 districts) submit their own water quality data as fulfillment of the EAA-EPD Bubble permit.

The Master Permit was issued by the SFWMD based on a demonstrated reasonable argument that the load reduction targets would be met through the implementation of phosphorus reduction credit (PRC) projects. The permit term is through January 16, 1997 and allows no net increase in activities that would result in a net increase in phosphorus loading to the lake.

The three projects implemented by the EAA-EPD and their corresponding phosphorus reduction credits are:

(1) *Volume reduction pump Best Management Practice (Pumping BMP):* 3.38 tons from implementation of BMPs in all basins (except S-2 and S-3, because of potential adverse impacts to the Interim Action Plan).

The EAA-EPD implemented the Pumping BMP throughout drainage basins tributary to Lake Okeechobee. The overall objective of this BMP was to reduce the long-term average volume of drainage pumping, which would lead to a reduction of total phosphorus loading from the EAA-EPD.

(2) *Deep well injection of treated effluent from local Publicly Owned Treatment Works (POTWs):* 5.14 tons from the diversion of discharges from three municipal wastewater treatment plants to deep well injection in Belle Glade, Pahokee and South Bay.

The cities of Belle Glade, Pahokee, and South Bay operate POTWs. The EAA-EPD implemented a deep well injection system with the intention of reducing total phosphorus associated with the elimination of municipal wastewater effluent discharges tributary to Lake Okeechobee for these POTWs. Prior to the deep well injection system, phosphorus loads were conveyed to Lake Okeechobee from the POTWs.

(3) *Modifications to the Clewiston Sugar Mill surface water system:* 1.5 tons from revised water management practices at the sugar mill in the S-4 Basin.

The Clewiston Sugar Mill implemented improved water management practices during the harvest season of 1989 that resulted in the reduction of drainage pumping during the mill season. Since the issuance of the master permit, additional improvements to water management at the Clewiston Mill have taken place. These improvements consisted of the construction of a 285 acre above-ground detention pond that is designed to detain runoff for a 25 year - 3 day storm event.

On July 28, 1994 SFWMD Staff completed a review of the Pumping BMP, POTWs, and Clewiston Sugar Mill. The reports documented that the PRC projects have been implemented according to permit conditions. The reports, together with monitoring data available at that time, indicated that the PRC projects resulted in the required 10 ton reduction of phosphorus loading to Lake Okeechobee. However, all water quality monitoring, research, and reporting required by the permit special conditions shall continue on schedule for the remainder of the permit term (January 16, 1997), unless a written agreement is reached between the SFWMD and the permittee or revisions are submitted and subsequently approved through a formal permit modification. Any modification of Permit No. 50-00001-Q (master permit) would need to provide assurance of continued compliance of Special Condition No. 12 of the master permit that requires no net increase in total phosphorus discharge concentrations of subbasin drainage be allowed, unless measures are taken to offset any such increase.

B1d. Interim Action Plan

The Interim Action Plan (IAP) was first implemented in 1979 to reduce nutrient loading to Lake Okeechobee from the EAA-EPD. The objective of the plan was to divert as much nutrient-rich water away from the lake as possible and direct it southward towards the WCAs, while maintaining an adequate level of flood protection in the EAA-EPD. The IAP has been successful in reducing the amount of nutrients that would have otherwise been pumped into the lake, and has exceeded its original goal of a 90% reduction in nitrogen loading from the EAA-EPD. An additional benefit has been the reduced phosphorus loading to the lake. The nutrients diverted from Lake Okeechobee were sent to the Everglades WCAs under this plan. Currently planned Everglades Restoration activities will allow for the diversion of some nutrient rich waters to STAs, which should further reduce backpumping. Current and planned strategies for reducing the backpumping program are described in Section 4c.

B1e. Control of Wastewater Facilities

In 1991, the SFWMD authorized $1.5 million for funding the planning, design, and construction of water and sewer infrastructure for Okeechobee County and adjacent areas, including Buckhead Ridge in Glades County. These other north shore areas currently use packaged wastewater treatment plants and numerous septic tanks. By September of 1995, the Okeechobee Utility Authority (OUA) had been established for the purpose of combining all public water and wastewater infrastructure services. Since that time, design for an expanded wastewater treatment facility has been completed and the OUA is moving forward to double its capacity for wastewater treatment. The existing disposal method provides irrigation to citrus groves and hayfields (reuse). Expanded reuse is proposed for the additional flow to address the area's critical water quantity and quality concerns.

Glades County and the City of Moore Haven, in May of 1995, formed a Joint Sewer Utility Authority for the purposes of providing sewer service to the City of Moore Haven and the US Hwy 27 commercial corridor currently not being served. This Joint Sewer Utility Authority was formed through cooperative assistance funding from SFWMD and has successfully completed construction of initial sewer facilities. The Authority is pursuing further development of infrastructure which includes an extensive reuse system in order to address concerns regarding water supply, water quality, and economic development.

B1f. L-8 Basin Diversion Works

The L-8 Basin improvements (L-8 Diversion) are intended to redirect runoff from the northern part of the L-8 Basin to Lake Okeechobee. There are two phases to the L-8 basin improvements. The proposed modifications for Phase I consist of construction of a new divide structure in the L-8 Borrow Canal at or near the southerly boundary of the J.W. Corbett Wildlife Management Area, renovation of existing Structure S-76 to add control facilities necessary for automatic and remote operation, and modification of the J. W. Corbett Wildlife Management Area structures to ensure adequate drainage. Phase II consists of construction of a new stormwater pumping station (S-309) on the L-8 Borrow Canal to Lake Okeechobee. Phase I detailed design was completed in November 1995 and Phase II detailed design is scheduled for completion in January 2003. Discussions about the efficacy of this project are currently underway, as this source of water may be better used for other purposes in this system. A modeling exercise was conducted to determine if this new water source, with its projected relatively low phosphorus load, would alter the overall achievement of the phosphorus loading target set by the Vollenweider model (described in the next section). No significant gain in reaching the phosphorus loading target was realized unless the small portion of agricultural runoff in the northern part of the basin was removed from the loading estimates.

B2. Effectiveness of the Management Programs

The collective effect of the management programs has led to a decrease in the phosphorus load to Lake Okeechobee, but have not met the target values determined from the modified Vollenweider model (Vollenweider 1976, Federico *et al.* 1981; data presented in Table 5) as shown in Figure 3. Five-year rolling averages help visualize trends without the year to year variability that interferes with visualizing the data. The average is computed for a 5-year period that advances one year and deletes the oldest year as data become available.

The target loading rate is a function of the amount of water entering the lake and the length of time the water resides in the lake. Figure 4 focuses only on the over-target load, which shows a pattern of decline through 1991, leveled off during the next few years, and then shows an increase in 1996 to 136 tons over the target. This upturn is caused by the 5-year rolling average calculation, which no longer includes the below-target year of 1991, and includes the high loading experienced in 1995, as well as the much smaller, but still above target, load in 1996 (Table 5).

Observations from several years of water quality data indicate that during the rainy season, the loading increases dramatically. This is best illustrated by observing monthly averages for the period of record (Figure 5). In the dry season, there are about 25 tons per month entering the lake, while in the wet season this amount more than triples. In 1995, the extraordinary amount of rainfall in October caused a tremendous increase in loading compared to the average (Figure 5). For the year as a whole, 1995 was 286 tons above the target.

To evaluate the effectiveness of the various programs, monitoring data are collected and used at two scales: (1) the outflow point from an individual parcel of land or dairy operation; and (2) at the outflows of the basins that flow into the lake. Analysis of data at these two scales shows that individual BMPs are effective; however, most basin loads still remain above their target concentrations.

B2a. Individual Parcels

Implementation of the Dairy Rule has significantly improved water quality in monitored discharges from dairies located within the TCNS and LKR basins. Prior to implementation of the Dairy Rule, only four dairies met the target goal (1.2 mg/L). Evaluation of selected dairy sites in LKR and TCNS (Havens *et al.* 1996d) provided strong evidence that dairy BMPs on individual parcels (Table 6) are effective. The Dairy Buy-Out Program was evaluated and also shows evidence of being effective in reducing the phosphorus concentrations from those site (Table 7).

Table 5. Loading of phosphorus to Lake Okeechobee. Actual load and target load generated from the Vollenweider model, over-target (difference between actual and target) and 5-year rolling average given for the over-target. Data are used in Figure 3 and 4.

Figure 3. Lake Okeechobee phosphorus loading. Five-year rolling average generated from the Vollenweider model for the target and actual load for 1977-1996.

Figure 4. Lake Okeechobee phosphorus loading over-target. Data generated by subtracting actual from the target concentrations.

Figure 5. Average monthly phosphorus loading to Lake Okeechobee. Data generated by averaging monthly loading (Jan=1, etc.) from 1972-1994. Data from 1995 are illustrated separately, showing the influence of a wet season followed by extreme rainfall in October that elevated the overall loading values for the year. (Historic rainfall from S-70, S-133 and S65E)

Table 6. Effectiveness of BMPs. Pre-BMP vs. recent (1993-1994) total phosphorus (TP) at Taylor Creek/Nubbin Slough (TCNS) and Lower Kissimmee River (LKR) dairy sites.* (The p value indicates a 95% probability that the data are significant, from Havens *et al*. 1996d).

Region*	Category	TP (mg/L)	Significant Decline?
LKR	Pre-BMP	9.2	
	Recent	1.3	Yes $p \leq 0.05$
TCNS	Pre-Buy-Out	2.6	
	Recent	1.0	Yes $p \leq 0.05$

*only those sites with both pre- and post-BMP data

Table 7. Effectiveness of Dairy Buy-Out program. Pre-Buy-Out vs. recent (1993-1994) TP at TCNS and LKR dairy sites.* (The p value indicates a 95% probability that the data are significant, from Havens *et al*. 1996d)

Region*	Category	TP (mg/L)	Significant Decline?
LKR	Pre-Buy-Out	3.6	
	Recent	0.7	Yes $p \leq 0.05$
TCNS	Pre-Buy-Out	3.4	
	Recent	2.0	Yes $p \leq 0.05$

*only those sites with both pre- and post-BMP data

B2b. Basins

The 1989 Interim SWIM Plan set phosphorus targets for Lake Okeechobee based on average annual, flow-weighted total phosphorus concentrations for each basin. These values provide targets that are adjusted for variations in discharge. To calculate the load from each basin, the concentration is multiplied by flow and the excess phosphorus loads may be calculated based on the excess total phosphorus concentration and the current estimation of discharge. The most current estimate of loading and concentrations for the basins is given in Table 8, and illustrated in Figure 6.

Table 8. Phosphorus loading by basin in the Lake Okeechobee watershed. Average annual discharge, total phosphorus concentration (TP), and tons/year are averaged over the 5-year period (1990-1994). Target concentrations are from the 1989 SWIM Plan.

Figure 6. Contribution of phosphorus from the Lake Okeechobee basins.

Collectively, the concentration from these tributaries for the period following full implementation of BMPs (1990-1994) was approximately 0.22 mg/L. During this period, 20 basins had averages above their target concentrations, and 12 were below their target. Collectively, the excess loading averaged 115 tons per year based on flow and target concentrations for each basin. This measured load is very similar to the calculated value given by the Vollenweider model for this time period, although not identical.

The highest concentrations were found in the LKR basins, S-65D & 65E, and S-154, followed by the S-191 (TCNS) basins, where dairies are abundant and where the majority of WOD sites that are out of compliance are located. These basins account for most of the over-target load, and, if they met their target concentrations, would collectively bring overall loading to Lake Okeechobee very close to the target. These basins currently receive intensive study, regulatory scrutiny, and are the focus of remediation activities, including the SFWMD/FDEP/Dairy industry effort to clean up dairy sites that discharge over 2.0 mg/L. These basins are also the focus of the landowner-based initiative described later in this chapter.

B2c. Phosphorus Review Panel

The SFWMD convened a four-day workshop in August 1995, with a panel of experts (Phosphorus Panel) to consider current and planned phosphorus management in the basin and to make recommendations on future management strategies. Technical presentations were made to the Phosphorus Panel and the public by the SFWMD staff and FDEP covering the programs that have been implemented in the basin, as well as research and monitoring efforts in the Lake Okeechobee watershed. Presentations were also given by the public and affected parties.

Following the presentations, the Phosphorus Panel convened five break-out sessions to gather more information, and these sessions were attended by SFWMD and agency staff, as well as the public and affected parties. A summary of the Phosphorus Panel responses to four key questions follows and the complete Phosphorus Panel report is included as Appendix H.

Question 1: Are Ongoing strategies in the watershed sufficient to reduce phosphorus loading to the SWIM Act target, and, if so, in what time frame?

The Phosphorus Panel concluded that the ongoing phosphorus control strategies are working, that phosphorus concentrations are decreasing in tributaries to Lake Okeechobee, and that activities to lower phosphorus loads to the lake should continue. Because the trend in phosphorus loadings is clearly downward, they did not believe that major new initiatives, such as requirements to install expensive new BMPs at the dairies (or at cattle operations or heifer farms), are justifiable at this time, and this is consistent with the RCWP findings for Nubbin Slough. The Phosphorus Panel also concluded that while loadings may continue to decline from installation of past BMPs, load reductions to the lake may begin to plateau, perhaps at a level higher than that desired, [current data presented in this SWIM Plan Update indicate that the loading has indeed leveled off higher than the target] and it is not unrealistic to predict that reductions from the strategies already being implemented could take a decade or more to be fully realized.

The Phosphorus Panel recommended that the SFWMD fine-tune its BMP implementation practices, that it focus on the less expensive BMPs for beef cattle, dairy, and heifer operations, and that it maintain an atmosphere of creativity in which the regulated community can bring its ideas and suggestions for solutions to the process. The SFWMD should continue its modeling studies that will address the question of strategy sufficiency, and those studies that will help determine the response of the lake to external and internal loads.

Question 2: Would better compliance with existing rules be sufficient to meet the target?

The Phosphorus Panel concluded, based on information presented and its understanding of rule compliance, that farmers and others in the Lake Okeechobee watershed are in compliance with the Dairy Rule and WOD rules as now enforced. They noted that the Dairy Rule requires only BMP installation without proof of performance and the WOD does not apply to dairies. They concluded that compliance with both regulations does not mean there is not room for improvement in reducing phosphorus loading from utilizing these existing programs. A key to maintaining the reductions already achieved will be the continued effort of the SFWMD to implement its WOD Program. While more aggressive enforcement of these rules may provide some additional reductions, it was not the Phosphorus Panel's opinion that significant expansion of this strategy would be the most effective use of limited resources. Maintaining the working relationships already established with the landowners is as essential to achieving continued cooperation and load reductions as is involving them in the development of new rules.

The Phosphorus Panel also believes that there has been too little time to judge the long-term effectiveness of phosphorus control practices (PCPs) that have recently been put into place to achieve SWIM load targets. The Phosphorus Panel recommended that only low cost and modest operational changes to PCPs at dairies be required when seeking to assure compliance with existing rules.

Question 3: What additional proposed strategies (recommended by SFWMD staff) are likely to be most effective for further reducing phosphorus loads?

The Phosphorus Panel concluded that four of the ten phosphorus (and nitrogen) control strategies considered by SFWMD staff should receive high priority for implementation: (1) Develop BMPs for cattle; (2) Remediate hot spots; (3) Reduce or eliminate backpumping to the lake; and (4) Create incentives for reduction of phosphorus [and nitrogen] imports to the watershed. Two of the ten strategies should receive second priority, and they are: (5) Improve management or creation of wetlands; and (6) Augment biological treatment of animal waste programs. Third priority were (7) Utilize chemical and biochemical treatment of animal waste programs; and (8) Evaluate in-lake measures to reduce phosphorus. An exception to this third priority ranking is "Water level management" which is considered an in-lake measure. Evaluation of this practice should be first priority. No priority was assigned to (9) Remove contaminated sediments in tributaries, because this strategy should be evaluated further, and the strategy to (10) Implement aquifer storage and retrieval or deep well injection, should be eliminated from further consideration because, in the opinion of the Phosphorus Panel; its benefits are far outweighed by the potential negative impacts. Each of these potential future strategies is described in Sections 3f, and 4b-4e.

The Phosphorus Panel recommended that the strategies identified by SFWMD staff be considered for implementation in the priority order given. They also recommended that strong consideration be given to the costs each strategy could impose on those regulated, as well as the associated phosphorus and nitrogen load reductions actually achieved by their implementation. The point of diminished benefits (in terms of in-lake phosphorus concentration reduction) for costs incurred for phosphorus and nitrogen reduction via increasingly expensive BMPs needs to be carefully evaluated. The models and other tools already developed by the SFWMD relating land use and BMPs to off-site phosphorus loads should be refined to evaluate the impact of loads reductions on the in-lake phosphorus concentrations.

Question 4: What Other strategies would the Phosphorus Panel recommend for consideration?

Based on the regulatory situation perceived by the Phosphorus Panel, particularly the implementation of the Dairy Rule and the WOD, the Phosphorus Panel suggested a transition from the concentration-based approach of the WOD to a Waste Load Allocation (WLA) basis and recommended that the SFWMD give strong consideration to such an approach. This approach would require the determination (either measured or modeled) of the allowable phosphorus load from individual land parcels, with the caveat that all parcels would collectively add up to the allowable load to Lake Okeechobee. The opportunity exists for the SFWMD to move from its innovative approach for nonpoint source regulation based on concentration to another innovative approach based on waste loads. In addition, the SFWMD can consider nutrient loads from all sources in the drainage basin and internal to the lake.

To make this transition to WLA, the Phosphorus Panel recommended institutional and technical steps needed to support this approach. The Phosphorus Panel believed the approach must be supported by a series of information development steps including, but not limited to, the following: (1) an updating of phosphorus source inventory in the basin and lake; (2) further investigation of in-lake phosphorus processes to expand the focus of recently completed investigations, to permit better assessment of impacts from activities such as lake level changes, and to enhance the SFWMD's ability to determine lake recovery time; (3) development of ways to estimate off-site phosphorus loads through monitoring of phosphorus concentration and flow and modeling efforts that generate load estimates without requiring flow measurements; (4) development of a water quality information system consisting of monitoring (including citizen monitoring), data analysis and synthesis, and information transfer and insuring coordination between monitoring needed for compliance as well as model support; and (5) development of institutional rules needed to implement a WLA management system. This overall approach is similar to the Total Maximum Daily Load methodology, although daily loads are not measurable for phosphorus coming from nonpoint sources.

B2d. Economic Evaluation of Water Quality Programs

The programs designed to reduce phosphorus loading to Lake Okeechobee, the Dairy Rule, the Dairy Buy-Out Program, and the WOD Rule, underwent an economic evaluation to estimate the extent to which they impacted the economy of Okeechobee County and the region (Hazen and Sawyer 1995). The study focused on the impact of these programs on the economy as dairies left the area under the Dairy Buy-Out Program, the remaining dairies complied with the Dairy Rule, and as permittees complied with the WOD Rule. The potential economic impacts from improved water quality conditions of the lake were not included in this evaluation because ecological responses to these programs are not expected to be rapid; therefore, they were not evident during the implementation period. The evaluation involved collecting publicly available information and interviewing dairies and other affected businesses. The data collected from the evaluation were statistically analyzed to estimate the changes in sales, income and employment from 1987 to 1993 due to implementing these programs.

Several economic conditions occurred during the 1987 to 1993 period in which the water quality programs were being implemented. The local and regional areas were experiencing the impacts of a nationwide recession. Sixteen dairies closed their operations under the Dairy Buy-Out Program reducing the milk production of the area and the sales, income and, employment that it generated. Eighteen dairies were spending $40 million to construct barn modifications to comply with the Dairy Rule. Meanwhile, the WOD permittees were implementing measures to comply with the WOD Rule. These simultaneous shocks to normal economic growth directly influenced the methodologies chosen to estimate the economic impacts of the water quality programs.

The evaluation found that total income in Okeechobee County including wages and salaries, proprietor's income, profits and rents were 3% lower in 1988 than it would have been had the water quality programs not existed. The impact was highest in 1991 when total income was 8% lower than it would have been had the programs not existed. By 1993, the year when all investments were completed to comply with these programs, total income was 5% lower than it would have been had the programs not existed.

The net employment losses as a percent of the total county jobs (for part-time and full-time jobs in Okeechobee County, including self-employed persons), was 2% lower in 1988 than it would have been had the water quality programs not existed. The impact was highest in 1991 when net county employment was 6% lower than it would have been had the programs not existed. By 1993, the year when all investments were made to comply with these programs, employment was 4% lower than it would have been had the water quality programs not existed.

The percentage impacts in the regional area, including Okeechobee, Highlands, Martin and St. Lucie counties were one to three percentage points lower than the impacts estimated for Okeechobee County. Total income and employment were 2% to 6% lower than they would have been had the water quality programs not existed.

B3. Technical Questions on Phosphorus Control Strategies

Effective phosphorus control strategies can only be implemented if we understand the fate and transport of phosphorus in the uplands, wetlands, and streams of the watershed. Several research projects were conducted to develop the understanding of the movement of phosphorus in the watershed. The key results presented here have implications for the development of cost-effective and sustainable BMPs to reduce phosphorus loads from the watershed into adjacent aquatic systems. Additional research is needed in certain areas that we currently lack important information and are also described in this section.

B3a. Phosphorus Budgets

Early research indicated that improved pastures and dairies are the primary sources of phosphorus loads (McCaffery 1976). Phosphorus imports, such as dairy cow feed and pasture fertilizer, are the primary sources of phosphorus in the watershed. Total phosphorus imports in the northern watershed were estimated at 2,618 tons of phosphorus per year while phosphorus exports in milk, cows, and crops were estimated to be 836 tons per year (Boggess *et al*. 1995). Although much of this phosphorus is retained in uplands and wetland sediments, this imbalance in imports vs. exports continues to add to the build-up of phosphorus in the watershed. This analysis was based on data from 1985-1989, which is prior to implementation of the most recent management programs. A new analysis of the phosphorus budget is needed to update the previous one done by Boggess *et al*. (1995).

B3b. Phosphorus in Soils

The Lake Okeechobee watershed has sandy soils, and there were uncertainties about the amount of phosphorus that can be stored in the soil, the potential for leaching from the soil to the tributaries, and its subsequent transport to Lake Okeechobee. These uncertainties initiated the effort to determine what soil properties, management practices, and environmental conditions control the phosphorus retention in these soils and availability of phosphorus for crop uptake.

An analysis of the phosphorus content and chemical characteristics at several dairy, pasture, and native sites in the TCNS and LKR showed that accumulated phosphorus was due to continuous manure loading. High phosphorus content in soils was related to dairies and improved pastures. For surface soils, the mean phosphorus storage was 680, 67, and 13.8 kg/acre phosphorus for the areas with HIAs, pastures, and non-impacted areas, respectively (Graetz and Nair 1995). Between 20 and 50% of the phosphorus stored in the HIAs was considered potentially mobile (Graetz and Nair 1995, Wang *et al.* 1995). However, due to slow ground water movement, this phosphorus has remained on-site. The potentially mobile phosphorus can be expected to leach from the soil over a long period of time, and Mansell *et al.* (1995) estimated that it would take 12 years to leach this form of phosphorus from the pasture soil profile by rainfall.

Based on the findings of this research, soil amendments were demonstrated to be a means of phosphorus retention on highly loaded soils. Using calcium carbonate and gypsum as soil amendments (Anderson *et al.* 1995), application rates of 10.7 tons gypsum/acre produced a 50% reduction in phosphorus. In addition, gypsum appeared to suppress bacterial biomass and mineralization of manure, particularly under anaerobic conditions.

B3c. Phosphorus Transport

Phosphorus transport through streams and wetland systems was simulated by the Phosphorus Transport Model (PTM) (Wagner *et al.* 1996). The model consists of a field-scale component, an in-stream phosphorus transport component, a hydraulic component, and interface programs that transform output from the field-scale component into input for the phosphorus transport component.

The PTM was applied to the Taylor Creek Basin (Zhang e*t al.* 1996a) and gave close estimates of flow and phosphorus loadings on a seasonal basis. Phosphorus assimilation within the transport system was also analyzed using the transport model (see Phosphorus Assimilation section). Future studies will examine the effectiveness of land use changes and BMPs for phosphorus load reduction to Lake Okeechobee.

At the field scale, phosphorus may be transported via surface and subsurface flow. In sandy soils with high infiltration rates, the occurrence of surface runoff is determined by available soil water storage, which is controlled by surface relief and drainage, and depth to the spodic horizon. The spodic horizon is a soil layer that can immobilize phosphorus, thus preventing its further movement in soil. Where the gradient is high, phosphorus is transported by subsurface flow, while at locations with low gradients, which are normally very wet, phosphorus is transported by surface runoff (Campbell *et al.* 1995). Results indicated that surface runoff from poorly drained sites, i.e., in areas where the spodic horizon is shallow, the phosphorus is easily transported due to limited interaction with the soil (Campbell *et al.* 1995). An improved hydrologic simulation model, the Field-scale Hydrologic And Nutrient Transport Model (FHANTM) (Tremwel 1992), was developed to better predict field scale phosphorus transport, and evaluate the factors affecting phosphorus transport.

FHANTM is currently being used in the Lake Okeechobee watershed as a tool to evaluate effectiveness of BMPs implemented on parcels out of compliance with the WOD Rule (Gornak and Zhang 1997). The product of this modeling effort, along with water quality and soils data in a technical assessment of the permitted parcel, becomes the technical and regulatory basis for the SFWMD to recommend entering into a consent agreement with the landowner to implement BMPs.

B3d. Phosphorus Assimilation

The WOD Rule (Rule 40E-61, F.A.C.) was developed after considering the allowable phosphorus assimilation capacity of wetlands, streams, and ditches within the Lake Okeechobee watershed. The rule allows landowners to discharge water with total phosphorus concentrations up to 1.2 mg/L, which is higher than that allowed for direct discharge to the lake (0.18 mg/L). A phosphorus assimilation coefficient was developed for the TCNS Basin (see 1989 Interim Lake Okeechobee SWIM Plan, pg. 86 [SFWMD 1989]) to determine the maximum average annual total phosphorus concentration allowed in off-site discharge. This value was developed as a basin-wide average, and at this time needs to be re-evaluated. Due to lack of available field and experimental data, the SFWMD agreed to conduct additional research and analysis to further assess the "A" value and provide a detailed, scientifically-based analysis of phosphorus assimilation. The SFWMD also agreed to provide a procedure for calculating site-specific coefficient values for individual sites.

Several studies were conducted to evaluate phosphorus assimilation: (1) a survey of two wetlands receiving high phosphorus loads; (2) a study of phosphorus assimilation in sediment columns; and (3) an evaluation of phosphorus retention in constructed channels. An additional study (4) synthesis of available data, was conducted to review various methods of estimating phosphorus assimilation. In summary, the findings of these studies determined that phosphorus utilization and deposition in the wetlands, canals and streams is a process that serves as a sink for phosphorus.

In study (1), an analysis of the phosphorus storage capacity of uplands, wetlands and streams indicated that about 80% of the total phosphorus imported into the LKR and TCNS basins was retained in uplands (Reddy *et al.* 1996). An additional 10-15% of the total phosphorus was retained in streams and wetlands. Most of the phosphorus was retained in non-available forms of soil phosphorus, and only about 1% of the total soil phosphorus was stored as labile phosphorus. At current loading rates, uplands have about 75% of their storage capacity remaining, compared to 45% in wetlands and streams.

In study (2), chemical precipitation of phosphorus appeared to be a minor process in native streams and wetlands because precipitation is more than 75% reversible (Diaz *et al.* 1994). Phosphorus retention in sediment was evaluated by measuring phosphorus uptake by undisturbed sediment cores. Phosphorus retention increased linearly with phosphorus loading up to a concentration of 6 mg phosphorus L^{-1}, with up to 88% of added phosphorus retained by sediments. When wetland soils and stream sediments were in contact with low phosphorus rainwater, less than 10% of the phosphorus was released from non-impacted sites, compared to 25% of the phosphorus released from highly loaded sites. The maximum phosphorus retention capacity was estimated to be approximately 70 g m^{-2} for wetlands, and 50 g m^{-2} for streams, which is more than 10 times the annual loading rate (Reddy *et al.* 1995b). The results of this study indicate that phosphorus retention by wetland sediments, receiving high phosphorus loads from agricultural sources, is an important phosphorus sink.

In study (3), artificial stream channels were constructed to evaluate the phosphorus assimilation in stream sediments subject to high flow rates. Over the course of the study, phosphorus retention in all channels was significant. An average of 4.4 mg phosphorus m^{-2} d^{-1}, or 14% of the inflow load was assimilated in the channels. Algal mats accounted for 30 to 50% of the phosphorus assimilated in unshaded channels. Algal phosphorus uptake was an important component of phosphorus retention, particularly in streams with nutrient-rich sediments. The results of this study indicate that phosphorus retention by wetland sediments, receiving high phosphorus loads from agricultural sources, is an important phosphorus sink.

Field and laboratory experiments were conducted to determine the phosphorus assimilation capacity of Otter Creek (Reddy *et al.* (1996), a stream with high phosphorus load originating from dairies and beef cattle pastures. Estimates of phosphorus assimilation indicated that the sediments assimilated approximately 5% of the phosphorus loads in this watershed. Although vegetation assimilates a significant amount of phosphorus during the growing season, approximately 60% of that phosphorus is lost during the winter. Laboratory experiments indicated that the sediment has a high capacity to assimilate phosphorus, but assimilation is limited by high flow rates and low contact period between the water and sediment.

At this point in time, the data indicate that the assimilation capacity used since 1989, is reasonable. The ability to estimate assimilation using the PTM (introduced in the Phosphorus Transport section above) was tested on the Taylor Creek basin (Zhang *et al.* 1996a). The annual average in-stream assimilation coefficient for the

Taylor Creek basin was 0.36, indicating that one-third of the phosphorus loading from upstream will be assimilated by the transport system. The transport system does not include on-site wetlands and field ditches. The PTM is being applied to other basins in the Lake Okeechobee watershed, and once completed, simulation results will be compared to previous estimates of assimilation coefficients for each basin over the next few years.

B3e. BMP Effectiveness and Comparability

To determine the effectiveness of individual BMPs, a systematic methodology for cross-comparison of alternative strategies for phosphorus load reduction, including field-scale, process-level, or basin-scale phosphorus reduction practices, needed to be developed. The need to evaluate practices at different scales resulted in the development of the Lake Okeechobee Agricultural Decision Support System (LOADSS).

LOADSS is a geographic information system (GIS)-based decision support system that provides a highly visual, graphic interface for water resources managers to select alternative land uses and land management practices, and BMPs for comparison (Negahban *et al*. 1994; Negahban *et al.* 1995). LOADSS contains databases for weather, soil, land use, hydrography, PCPs, economics, and political boundaries for approximately 1.5 million acres. It also contains estimates of long-term, average annual phosphorus loading values. LOADSS uses this information to perform optimization analyses that identify PCP combinations for reducing phosphorus loads while minimizing the economic impact of their implementation (Negahban *et al.* 1994). The optimization module also allows the SFWMD to evaluate tradeoffs between various environmental and economic actions that may be taken to meet these goals. LOADSS was developed with data collected during the mid-1980's and was calibrated only for Pre-Dairy Rule phosphorus loading conditions (i.e., BMPs were not applied to dairy operations).

To better represent today's activities in the watershed, the LOADSS model is being updated through contractor for the SFWMD (expected completion in 1998). This project will update the existing LOADSS database using the most current land use and economic information. Lake Okeechobee SWIM parcel boundaries developed for the WOD Rule will also be incorporated into the LOADSS database for conducting phosphorus loading analysis at a finer spatial scale and to more accurately describe land management practices.

In previous versions of LOADSS, the in-stream phosphorus assimilation coefficient for each subbasin was developed with CREAMS-WT land-based phosphorus loading estimates, subbasin target load estimates, and the average length of flow through streams and wetlands. LOADSS uses an assimilation coefficient based solely on travel length through streams and wetlands, however, recent studies by Wagner *et al*. (1996) and Reddy *et al*. (1996) show that phosphorus assimilation is related to both travel length and in-stream concentration values. This update will investigate the best methodology for estimating phosphorus assimilation along a subbasin's transport system (i.e., streams and wetlands). Also, assimilation coefficients will be estimated from measured loads instead of target loads. These modifications will enable more realistic simulations with LOADSS.

B3f. Research Needs on Phosphorus in the Watershed

B3f(1) Watershed coordination. The SFWMD has formed the Watershed Working Group, an interagency effort w/ FDEP, NRCS, DACS, Cooperative Extension Service, to pool and coordinate efforts to reduce phosphorus loading to Lake Okeechobee. Presently, the group is in the gathering/analysis of data stage and will be developing a work plan to assign responsibilities. The objectives of the Working Group are:

1. Serve as a technical information tracking clearinghouse.
2. Evaluate past and current information gathering and evaluation efforts.
3. Identify current unanswered questions about watershed processes and application to real world situations.
4. Evaluate existing information data bases and current data collection programs in context of gathering appropriate data to answer questions.
5. Identify information gaps and identify resources/ programs necessary to gather the appropriate information to fill the gaps.
6. Make formal recommendations to SFWMD and other agencies for appropriate information gathering, processing, evaluation, and analysis support.

B3f(2) Development of BMPs for beef cattle.

One program was initiated in 1995 to provide a predictive understanding of beef cattle agriculture as a nonpoint source of phosphorus, and to better define environmentally and economically sustainable agricultural practices. The SFWMD entered into a Memorandum of Understanding (MOU) with Archbold Biological Station and the Institute of Food and Agricultural Sciences (IFAS) at the University of Florida to conduct this agroecology research, which will include the development of a decision support system, and construction and analysis of experimental pasture arrays at MacArthur Agroecology Research Center (Buck Island Ranch). The Florida Cattlemen's Association has now become a co-sponsor of this agroecology research. The intent is to provide a tool for ranchers that allows them to conduct environmentally and economically sustainable agricultural practices. The experimental pastures are now constructed and stocking should begin in the 1997 calendar year. The Phosphorus Panel ranked this strategy as high priority.

B3f(3) Analysis of phosphorus in tributaries sediments. Phosphorus-enriched sediments in tributaries may be an important source of phosphorus that potentially contributes to the phosphorus loading to the lake. A study has been initiated that is approximately 90% completed, that will provide an accurate estimate of the amount of phosphorus reaching the lake that can be attributed to tributary sediments, including tributaries ranging in size from field ditches to primary canals. To make appropriate management decisions, it is important to determine the relative magnitude of phosphorus from these different tributary types.

Preliminary information from this study indicates that approximately 800 tons of phosphorus is located in a thin, surface layer in the 10 basins of the study area. These sediments are rich in organic material and are highly mobile. The second part of this study will document information about the location, areal extent, thickness (depth), phosphorus content, mobility of the different phosphorus forms, and the overall transportability of these sediments to the lake. The field portion of this more detailed study is completed. The circumstances that cause the movement of sediments or the phosphorus contained in these sediments will also be determined.

This information is important for developing potential management options, such as the removal of phosphorus-enriched sediments or other means of immobilizing this source of phosphorus. This may also result in improved land use practices designed to reduce the build-up of organic sediments in wetlands. This study is designed to provide the background information necessary to determine the need and feasibility of removing tributary sediments as a way to reduce phosphorus loading to the lake. Samples from 32 sites were also analyzed for metal and pesticide content to help determine disposal options. The Phosphorus Panel did not rank this program and stated that this strategy should be evaluated further after feasibility studies are complete.

B3f(4) Wetland restoration/creation. One of the potential mechanisms for reducing phosphorus loading to Lake Okeechobee is the restoration of existing wetlands, and/or the creation of new wetlands as filter marshes. Wetlands are efficient at trapping phosphorus and a variety of options exist in the watershed that include: vegetative flows, on-farm wetland restoration, riparian easements, and basin-scale artificial wetlands (filter marshes).

The acreage north of the lake ranges between 18-25% wetland (National Wetlands Inventory). Approximately 45% of these wetlands have been ditched to drain them. One potential program would be to reduce the number of drained wetlands by simply removing the connection between the wetland and the ditch, leaving the drainage system in place. This would allow surface runoff to drain as usual, with the added benefit of additional on-site storage in the restored wetlands. These wetlands in the watershed would be highly effective in:

1. water retention/detention for flood protection and peak flow attenuation
2. nutrient removal (a minimum of 25%, and upwards of 80%; this would be long-term removal except in highly loaded areas (Goldstein 1993)
3. wildlife habitat restoration

This potential program could be fostered by using incentives and facilitating landowner applications for funds from federal programs, such as the USDA-Wetlands Reserve Program, and Environmental Quality Incentives Program. The creation of large-scale filter marshes, such as those being used the EAA (Burns and McDonnell 1993), are most likely not feasible in the northern watershed of Lake Okeechobee; the large land area required to capture stormwater runoff and the location that would be needed for this type of solution are not readily available. Smaller versions of these filter marshes are currently being pursued and are part of the non-regulatory program for reducing loads to the lake that landowners are participating in.

B3f(5) Update phosphorus budget and explore incentives for reduction of phosphorus imports. One important project that was recommended by the Phosphorus Panel included an update of the phosphorus budget for the lake, which was last conducted on data from 1985-89. Several programs would benefit from this update, which measures imports of phosphorus for fertilizers, and feeds, and exports through milk and beef. The budget provides the basis for understanding how excess phosphorus is entering the Lake Okeechobee watershed. By reducing the net import of phosphorus into the watershed (amounts discussed in the Section 3), the potential exists for stopping the problem before it starts.

Fluck et al. (1992) lists potential management strategies for reducing imports of phosphorus that could be considered for the Lake Okeechobee Watershed. These include:

1. Reduction in the quantity of imported dairy cow feed
2. Reduction in phosphorus concentration of imported dairy cow feed
3. Reduction in phosphorus fertilization application for improved pasture
4. Reduction in phosphorus supplements to beef cattle

The reduction in imported feed has been achieved by farmers growing more forage, with nutrients being supplied (at least in part) by dairy wastes. This on-site recycling of nutrients has been effective and is part of the BMPs utilized by dairy farmers. Feed imports were also reduced following IFAS research that demonstrated that phosphorus content might be too high (Morse 1989).

The second management strategy for reducing the phosphorus content in cow feed could not be fully implemented. The nutritional requirements for cows in heavy milk production requires a diet high in phosphorus in order to maintain cow fertility. However, feed imports were reduced following construction of semi-confinement dairies and feed barns, which reduced feed waste.

The phosphorus content on improved pasture soils has been measured in several locations throughout the basin (IFAS, Ona, FL), and shown to have sufficient phosphorus reserves in the subsoil for bahia grass growth without the need for additional phosphorus in fertilizers. An extension program is currently in place through IFAS to educate farmers on the use of fertilizers for improved pastures.

B4. Summary of Recommended Management Strategies for Controlling the Over-Target Phosphorus Loading

The strategies to reach the target phosphorus load to the lake are an integral part of the SWIM Plan Update and are described below. Details of each aspect of these strategies are described in the previous sections of this chapter.

Strategy 1: Implement non-regulatory, landowner-based initiative

The first strategy for controlling phosphorus focuses on the 4 over-target basins, which, if they met their target concentrations, would collectively bring overall loading to the lake close to the target. These 4 basins contain most of the dairies as well as the majority of WOD sites that are out of compliance. This would involve implementing volunteer initiatives with landowners for on-site retention of phosphorus and water. These measures include restoration of isolated and riverine wetlands in the watershed. This strategy starts with landowner involvement for developing on-site solutions. Detailed planning to implement solutions, including the design and engineering of projects such as wetland restoration, would be the next stage. Monitoring data should be collected before and after water implementation of these measures in order to gauge progress toward load reductions.

One of the key programs that is the restoration of wetlands in the watershed (see previous section 3f (4). Many wetlands in the watershed were once isolated depressions that functioned as small water retention areas in the landscape. Others were more expansive, and all have experienced drying from the regional drainage system. The current system causes the loss of water from the watershed as surface water runoff and groundwater flow to canals, which is rapidly transported to the tributary system that drains into Lake Okeechobee. Restoration of these drained wetlands in the northern watershed of Lake Okeechobee, as well as create new ones to retain/detain the water in the watershed, would slow the runoff and attenuate peak flows. For the ditched wetlands, the approach will be to simply remove the connection between the wetlands and the ditch, leaving the drainage system in place. In addition to water storage, these wetlands would remove nutrients and restore wildlife habitat.

Strategy 2: Remove tributary sediments that are rich in phosphorus

Sediments in tributaries to Lake Okeechobee are an important source of phosphorus that contribute to the over-target loading to the lake. Although our knowledge on the transport of these sediments to the lake is limited at present (see previous section 3f(3) of this chapter), it is certain that high flow conditions will mobilize a portion of the sediments. Sediments were found to have the highest concentration of phosphorus in the upper 6 inches, and are located predominately in the primary and tertiary canals (80% of the 800 tons). This strategy would dredge sediments from these canals, thereby removing them as a potential source of phosphorus to the lake. The phosphorus loading to the lake would be reduced, enhancing the ability for the in-lake phosphorus target of 40 g/L to be achieved more rapidly.

Strategy 3: Develop Best Management Practices for improved pasture

Improved pastures for beef cattle are most likely the greatest source of phosphorus load to the lake. Because this source is important, BMPs for improved pasture management need to be developed with the long-term objective of lowering the phosphorus coming from the watershed (see previous section 3f(2). Although BMPs such as fencing and incentives were implemented during the TCNS RCWP, additional practices are necessary to achieve the required load reduction. These practices may include better management of stocking rates; improved grazing practices, including winter/summer range rotation; and rotation grazing to ensure biomass and nutrient management. Each of these practices would reduce manure accumulations and promote uniform utilization of the resources.

One cross-cutting effort that is best listed here is the development and application of watershed modeling approaches for phosphorus transport and load reduction scenarios. Several models are in use, being updated or under development, that provide information on management strategies. These models work on a variety of scales, ranging from the entire watershed and/or basin, down to the individual parcel that a landowner has under permit. These models are an integral part of the solution to reducing phosphorus loading to the lake.

Strategy 4: Continue to implement the regulatory programs and monitoring

Works of the District-All of the permitted parcels located in the 14 priority basins have been assessed for compliance (see Appendix C, pg. 148 for a flow chart of the entire permitting process). Those parcels requiring corrective actions have been identified. Staff has, or is currently assessing permits that are exceeding average annual phosphorus targets to determine which parcels are not in compliance as a result of on-site activities. A formal notification of potential non-compliance is sent to owners of parcels that are discharging surface waters with high phosphorus concentrations. Once non-compliance is confirmed, a permittee is required to develop a corrective action plan with an implementation schedule. This plan is incorporated into their SWIM permit as a Permit Addendum Modifications (PAM). If SWIM phosphorus limitations are not achieved within one year of issuance of the PAM, additional corrective actions are required. The effectiveness of identified corrective actions is evaluated using existing water quality and soils data along with the FHANTM model. This information is documented in a formal Technical Assessment and initiated through a Consent Agreement between the SFWMD and the landowner.

For the WOD sites that are out of compliance (OOC), corrective actions that are currently used are:

- Remove residual phosphorus in soils in former HIAs through a nutrient management program of forage production (Sorghum, Oats, Bahia, and Alicia Bermuda and improved grasses) with subsequent harvest and export
- Develop grassed buffer areas around existing areas where animals congregate
- Minimize or eliminate the development of new animal congregating areas by mobilizing shade, water and feeding areas and placement of these areas away from tributaries in well-drained sandy areas
- Eliminate cattle from tributaries and develop rotational grazing strategies that move cattle away from sensitive areas during the peak rainfall periods
- Eliminate phosphorus fertilizer applications near tributaries
- Limit the over-drainage of wetland soils
- Restore wetlands that have been ditched or drained
- Reduce animal density (voluntary)
- Reduce phosphorus import in animal feeds
- Use lime to improve soil-binding capacity and enhance availability of phosphorus for plant uptake
- Use IFAS soil testing data and subsequent fertilizer application recommendations to optimize plant growth and minimize nutrient runoff
- Eliminate off-site discharge from areas with high density of animals
- Scrape sediment and remove off-site or spread in upland areas
- Use a combination of chemical and biological treatment of hot spot ditches
- Ditch maintenance, remove and spread sediments in upland areas
- Drag and spread manure to reduce the accumulation of manure in high traffic areas to distribute nutrients more evenly across the pastures
- Develop balanced phosphorus budgets for areas requiring corrective actions

As of May 1997, the WOD non-compliance activity summary includes six Early Warning Letters, thirty PAMs and six Consent Agreements. Fourteen permittees that have initiated corrective actions have achieved the SWIM phosphorus limitation for their respective land use. Eleven of the permittees that have developed corrective actions in accordance with their PAM have since achieved their off-site phosphorus limitation. The remaining two permittees have achieved compliance following the implementation of corrective actions called for in their respective Consent Agreements.

Modeling was used to determine the load contributed by OOC sites (Zhang and Essex 1997). OOC sites are defined as having runoff with average total phosphorus concentrations exceeding the discharge limitation for a twelve-month period (October 1994 to September 1995). Fifty-seven OOC sites were identified within the Lake Okeechobee watershed. The magnitude of potential phosphorus load reduction was estimated from CREAMS-WT simulations and measured phosphorus concentration at 17 tons to Lake Okeechobee.

Improved Dairy Performance- The Dairy Rule is technology based, and instead of target concentrations for phosphorus, it places reliance on implementation of waste control systems around milking barns, and pasture management procedures on the rest of the farm. Thirty dairy barns in the basin originally completed and began operating these required systems. They have been operational since 1991. The FDEP conducts site visits to the dairies and suggests improvements to the current operating procedures to improve water quality. In reporting the biweekly water quality results, the latest update for 12 month average (December 1996 report) shows that 9 dairies >1.2 mg/L, while 15 dairies are meeting the SWIM target. The dry year took several off the list due to no observed flow during the 12 month period. Of those that do not meet targets, five dairies consistently discharge surface runoff with phosphorus concentrations that are above 2.0 mg/L.

A project was recently completed in 1995 that performed a technical assessment of 10 discharge sites on these 8 dairies. FDEP, the SFWMD and the dairies all worked together and contracted with Soil and Water Engineering Technology, Inc. (SWET) to evaluate and recommend appropriate actions to eliminate excess (consistently above 2.0 mg/L) phosphorus runoff from 8 dairy. The SFWMD funded this study, provided the results to FDEP for implementation, and have continued to work closely FDEP staff on this program. The FDEP adopted the Final Report by SWET, and is now requiring dairies to implement the recommendations as a specific condition for permit renewal. Two dairies have already come into this process.

As part of ongoing efforts to meet the target, the potential for further phosphorus load reduction from dairy farms, improved pastures, and other sources were investigated by the SFWMD, in addition to the above technical assessment. This study utilized CREAMS-WT to provide a preliminary assessment of the upper limit of runoff phosphorus load reduction possible from contaminated dairy sites (Zhang *et al.* 1996b). Contaminated dairy sites were defined as having runoff with an average total phosphorus concentration exceeding 2.0 mg/L for a three-year period (October 1991 to September 1994). Fifteen contaminated sites were identified within the Lake Okeechobee watershed. Based on CREAMS-WT simulations and a GIS database, these contaminated sites contributed an estimated 9.3 tons of phosphorus to the lake on an average annual basis. If phosphorus concentrations in runoff did not exceed 1.2 mg/L, the discharge limitation for dairies, an average of 6.3 tons of phosphorus load reduction would be expected.

Reduction of Backpumping-The IAP has been successful in reducing the amount of nutrients that would have been pumped into the lake and has exceeded the original goal of a 90% reduction in nitrogen loading from the EAA-EPD. The nutrients diverted from the lake were sent to the Everglades WCAs under this plan. The phosphorus tonnage peaked above 70 tons in 1978 and now averages 10 tons (Figure 7). Continued efforts should be made to decrease the phosphorus load from the EAA-EPD.

Florida's Everglades Forever Act of 1994 set into action a plan for restoring the Everglades ecosystem (373.4592 F.S. 1994). Two components of the Everglades Construction Project provide for the reduction of phosphorus to Lake Okeechobee. Presently an average 36,400 acre-ft/yr of stormwater runoff (1990-1994) from combined agricultural and urban sources discharge directly to Lake Okeechobee from the 298 districts. These districts will complete conveyance system modifications sufficient to redirect approximately 80% of this runoff to the SFWMD's primary canal system for subsequent treatment in the STAs rather than discharging into Lake Okeechobee, which will eliminate approximately 10 tons/yr. These diversions will be phased between 1999 and 2003 (Everglades Program Management Plan, 1995). Additionally, a control structure and pump station will be constructed or modified to redirect approximately 51,000 acre-ft/yr of runoff from the relatively pristine northern L-8 Basin watershed to Lake Okeechobee. Preliminary modeling of this project has shown a slight improvement in meeting the phosphorus loading target as a result of this project.

Monitoring-Monitoring data are an integral part of the watershed efforts to control phosphorus loading, used in both the WOD and Dairy Rule programs. These data provide the basis for any changes required by landowners. Monitoring ambient and inflow data are also used to determine compliance with the SWIM Act, and also identify basins that need additional, more detailed analysis if they are above their target.

C. WATERSHED MANAGEMENT ISSUES-OTHER WATER QUALITY PARAMETERS

The FDEP considers tributaries, canals and contiguous wetlands that connect to navigable waterways, to be waters of the state, and at the point of entry to Lake Okeechobee, all applicable surface water quality standards may apply, as outlined in Chapter 62-302, F.A.C. The water quality standards have numeric values for various physical and chemical parameters that protect the beneficial uses of the water for potable water supply (Class I), aquatic life use (Class III), and agriculture (Class IV). The SFWMD is required to obtain a permit from the FDEP for the operation of all water control structures leading into and out of the lake. As part of the permit renewal process, the SFWMD is required to develop strategies and implement programs for protecting and restoring the beneficial use of waters of the state as well as the tributary basins leading to the lake. In response to these requirements, the

Figure 7. Phosphorus loading from back pumping (S-2 and S-3). Data are 5-year rolling averages of the total phosphorus loads.

SFWMD funded the "Lake Okeechobee Class I and Class III In-Lake and Inflow Water Quality Monitoring" study (CH2M Hill 1995), summarized below.

C1. Review of Data

The water quality monitoring study was initiated by the SFWMD in October 1991 and completed in 1994. All historical (1973-1992) lake and tributary inflow water quality data were evaluated to determine the level of compliance with numeric state water quality standards. Sample locations included 9 in-lake stations (the in-lake findings are described in section D, In-Lake Water Quality Issues), and 33 tributary stations located at all SFWMD and USACE-maintained water control structures; locations along the Kissimmee River, TCNS, Harney Pond and Indian Prairie canals, Fisheating Creek; all Everglades Protection District structures which drain into the lake through pump stations or culverts including the four Chapter 298 districts and Closter Farms. In addition to the SFWMD's historical data, more than 60 previously unsampled water quality and biological parameters were collected during a 12-month monitoring program at the same 42 stations mentioned above.

An evaluation of these data from the 20-year period of record indicated that the lake and its major inflows generally comply with applicable state water quality criteria. Exceedances of water quality criteria for most monitored parameters generally represented less than 25% of the measurements at specific locations. Criteria exceedances due to low dissolved oxygen (DO) and iron concentrations were more frequent at many of the inflow locations. However, most of the iron exceedances were based on the secondary drinking water standard rather than the criterion for protection of aquatic biota. Criteria exceedances for trace metals and organic contaminants were rare in the lake inflows. Based on the observed criteria exceedances, water quality associated with inflows has not substantively impaired the designated uses of the lake. However, additional monitoring of biological conditions is recommended to document whether the lake and its inflows meet their designated uses.

Parameters with widespread or frequent exceedances included pH, alkalinity, chloride, DO, turbidity, un-ionized ammonia, and iron. Cadmium, lead, mercury, and zinc are included in this section because of their potential to impact aquatic resources in the lake, although data for those trace metals is very limited at most stations. Exceedances of pesticide criteria were infrequent during the quarterly sampling in the supplemental monitoring program, but pesticides and other organics are included in this evaluation because of the very limited database and because of their potential for ecological impacts.

C1a. pH

The criteria for pH include a minimum value (6.0) and a maximum (8.5), unless natural background conditions are documented to be lower or higher. The criteria were developed primarily to protect aquatic life. Some exceedances of pH criteria were observed at most of the inflow stations, although the exceedances represented less than 25% of the data. Exceedances of both low and high-pH criteria were seen at inflow stations. The Fisheating Creek inflow station, FECSR78, had many low-pH values. The low pH values at FECSR78 appeared to be associated with humic and fulvic acids from wetlands in its drainage basin. The exceedances of pH criteria appear to reflect naturally occurring processes in the drainage basins.

C1b. Alkalinity

The criterion for alkalinity requires a minimum value of 20 mg/L as $CaCO_3$. Alkalinity buffers pH changes, and the bicarbonate and carbonate that contribute to alkalinity can complex some trace metals and reduce their potential toxicity to aquatic organisms. Low alkalinity can inhibit shell formation by aquatic snails and other mollusks. The most frequent occurrence of low alkalinity values was generally associated with low pH at inflow locations on the west side of the lake. Low alkalinity appears to be a natural condition in the inflow systems where it was documented.

C1c. Chloride

The Class I chloride criterion (250 mg/L) is based on drinking water concerns, as high levels of chloride can give drinking water a salty taste. No Class III chloride criterion has been established. Chloride exceedances were documented at nine inflows located along the southeast shore of the lake; shallow groundwater in that area is affected by chloride and other salts that remain from the Pleistocene Era, when much of Florida was covered by shallow seas (Schroeder *et al.* 1954). No in-lake stations showed chloride exceedances. Therefore, the high-chloride inflows appear to be related to groundwater seepage into the canals, and they do not appear to impact the use of the lake as a source of drinking water.

C1d. Dissolved Oxygen

Adequate levels of DO are necessary for aquatic animals to respire; the Class I and III criteria require a minimum of 5.0 mg/L, and the Class IV minimum is 3.0 mg/L. DO exceedances (less than 5.0 mg/L) occurred at all of the inflow stations, where they represented from less than 25% of the measurements (S308C, S135, and S84) to 75% or more of the values (CULV12A, CULV5, and S154C).

Many of the inflow stations showed a tendency for more DO exceedances to occur when flow was toward the lake than when there was no flow, especially for stations at the south end of the lake. This may be due to seepage of low-DO groundwater into canals during pumping events. Canal water levels can be drawn down faster than groundwater levels by pumping at control structures, with the result that groundwater seeps into the canals. Groundwater typically has low DO levels, which would tend to reduce the DO levels in the canals. However, no studies have been conducted to document whether seepage into canals has a significant impact on surface water DO concentrations during pump events.

Dissolved oxygen fluctuates naturally in waterbodies because of many physical and biological factors. The data collected on DO is done on a snap-shot basis, and the time of sampling can have an impact on the values. DO values during extended periods of no flow at a structure can also play a role. Chronically low DO values can be the result of anthropogenic influences, but they can also be a natural characteristic of wetlands and other low energy systems. Schwartz (1985) concluded that the low DO values in TCNS, Fisheating Creek and the Kissimmee River systems were due to drainage from extensive wetlands systems in their basins. Loadings of oxygen demanding substances and groundwater seepage into the drainage systems around the lake also may contribute to the low DO values documented in the inflows. Although in-lake DO problems do not exist, additional monitoring may be needed to determine the significance of the potential causes of low DO before management strategies are evaluated.

C1e. Turbidity

Turbidity exceedances were evaluated with respect to "background" values; the criterion allows a maximum of 29 Nephelometric Turbidity Units above background. Background turbidity for each station was estimated as the median value from that station. Exceedances were infrequently observed at inflow locations compared to the in-lake stations. Therefore, watershed management strategies may reduce sediment loadings and turbidity levels in canals, but would not likely be effective at reducing turbidity exceedances in the lake.

C1f. Un-ionized Ammonia

Aqueous ammonia can be present as un-ionized ammonia (NH_3) and as ammonium ion (NH_4^+); un-ionized ammonia is the form that is toxic to some aquatic organisms. The criterion allows up to <0.02 mg/L NH_3. The proportion of un-ionized ammonia increases with increasing pH and temperature. Un-ionized ammonia exceedances were observed at many inflow stations, but they were generally infrequent. Ammonia is a naturally-occurring form of nitrogen in surface waters. However, where exceedances of the un-ionized ammonia criterion are frequent, they are most likely related to anthropogenic sources of nitrogen, such as land spreading of sludge and/or agricultural fertilizers.

C1g. Iron

Iron exceedances could affect the aesthetic value of drinking water obtained from Lake Okeechobee. The Class I criterion is 0.3 mg/l, based on the potential for staining and odor problems at higher levels. The Class III criterion of 1.0 mg/l is designed to prevent clogging of fish gills by flocculent iron complexes. Exceedances of the Class III criterion were observed at many of the inflow stations. The widespread distribution and frequency of high iron concentrations in the inflows indicate that this is a natural condition, although agricultural practices could contribute to elevated iron concentrations in surface waters by erosion of soils containing iron and applications of iron-containing fertilizers to crops.

C1h. Trace Metals (Cadmium, Lead, Mercury, and Zinc)

The historical data base generally had less than 20 observations each for cadmium, lead, mercury, and zinc at the inflow and in-lake stations. When the data for all four trace metals are combined, the inflow stations at the north half of the lake are seen to have high frequencies of exceedances. The inflow stations at the south half of the lake generally have much lower frequencies of exceedances for cadmium, lead, mercury, and zinc.

Exceedances of trace metal criteria are most likely to be due to anthropogenic sources, such as agricultural uses of sludge, fertilizers, and pesticides; burning of fossil fuels and wastes; and gasoline additives. Limited amount of trace metal data makes it difficult to evaluate the need to implement management strategies to reduce trace metal concentrations. Modification of the SFWMD's monthly monitoring program to could include trace metals with documented exceedances in the historical data. This would facilitate a more conclusive assessment of the occurrence of exceedances and the potential need for management measures.

C1i. Organics and Pesticides

Pesticides and herbicides might be expected in the inflow and in-lake samples because of the dominance of agricultural land uses in much of the Lake Okeechobee basin. During 1993-94, CULV10 was the only location with detectable levels of pesticides. Dieldrin and DDT exceeded criteria at CULV10 on two of the quarterly sampling events, and one toxaphene exceedance was documented. One exceedance of a polycyclic aromatic hydrocarbon criterion (2-methyl naphthalene) was detected at station CULV10A.

The results indicated that pesticides and other organic contaminants do not chronically exceed the criteria. However, those parameters were only sampled four times at each station during the Phase 2 monitoring program, and the seasonal application of pesticides and variations in transport to surface waters based on rainfall patterns could have affected the likelihood of detecting organic contaminants. Therefore, additional organic monitoring may be needed in conjunction with the SFWMD's existing monitoring program to allow conclusions regarding exceedances of criteria for pesticides, herbicides, and other organic contaminants. The list of organic parameters from the supplemental monitoring program should be reduced to focus on compounds that are known to have potential sources in the watershed, such as pesticides, herbicides, and petroleum hydrocarbons. Quarterly sampling for organics was recommended, and the schedule within each quarter should be based on seasonal uses of agricultural chemicals and/or periods of inflow to the lake.

C2. Recommended Class I/III Management Strategies for Tributaries

Based on existing land uses and water quality conditions in the Lake Okeechobee basin, several strategies for marinas and canals may be applicable to the lake inflows. In addition, constructed wetlands may be appropriate for most land uses, assuming the availability of land. Alternative criteria could also potentially be established for some parameters in order to eliminate exceedances. A summary of the recommended procedure for each strategy is given in Table 9.

Table 9. Potential applicable management strategies.

Strategies for Canals	***Administrative Measures***
Oxygen Injection	Site Specific Alternative Criteria
Air Injection	Mixing Zones
Sediment Removal from Canals	
Constructed Wetlands	
Marina Operations	
Liquid Waste Management	
Boat Maintenance Control Measures	

C2a. Strategies for Canals

Three techniques have been developed for increasing DO in discharges from dams. These techniques could potentially be applicable to the canals and pumped water control structures that are commonly used to control surface water movement in the Lake Okeechobee watershed. In addition, sediment removal from canals and constructed wetlands provide management alternatives that could potentially be used for many land use categories in the watershed. *Oxygen injection* involves the use of pure oxygen to increase levels of DO in reservoirs. It could potentially be used to increase DO concentrations in the systems that drain to the lake. *Air injection* is similar to oxygen injection, but atmospheric air or compressed air is used to increase the DO concentration of the water body. It requires a compressor or other source of air, a diffuser system to distribute the air, and pipe to deliver the air to the diffusers. Air injection may not be effective for large volume, intermittent flood-control flows to the lake. *Spillways and weirs* could be constructed at the downstream sides of control structures to enhance aeration of water as it flowed over the structures.

C2b. Marina Operation Strategies

Marina and boat operations, such as disposal of liquid wastes, and boat maintenance and cleaning can generate surface water pollution. These management strategies could potentially be applicable to marinas on the lake. *Liquid waste management* involves providing appropriate facilities at marinas for disposal of liquid wastes, such as oil, waste gasoline, solvents, antifreeze, and paints. *Boat maintenance control measures* includes providing designated areas for boat maintenance and repairs, and requiring their use for those activities. It also calls for regular cleaning of the maintenance areas to remove trash, sandings, paint chips, etc. The goal is to reduce the amount of solid wastes that are introduced to surface waters.

Marinas and associated camping areas that have direct runoff into the lake from paved areas should develop and implement stormwater treatment systems. This would reduce the wastes associated with these recreation activities.

C2c. Administrative Measures

The F.A.C. includes provisions that allow for relief from water quality criteria under certain circumstances. Examples of such measures include site-specific alternative criteria and mixing zones. These alternatives differ from the management strategies described previously, because the administrative measures result in the elimination of criteria exceedances without improving water quality conditions. Site-specific Alternative Criteria may be approved for specific parameters in all or part of a surface water body. A mixing zone may be granted to allow alternative criteria for specific parameters within the zone of mixing, provided the applicable criteria are met at the edge of the mixing zone. Administrative relief measures would likely be viewed by FDEP as acceptable only after thorough demonstration that other alternatives to improve water quality conditions are not feasible because of technical or financial limitations.

Establishment of alternative criteria appears to be the administrative strategy that is most likely to be approved by FDEP. Surface water quality regulations contained in F.A.C. Chapter 62-302 provide for the establishment of site-specific alternative criteria in certain cases when a water body does not meet applicable criteria due to natural conditions or man-induced conditions that cannot be controlled or abated. In addition, the general criteria for surface waters (F.A.C. 62-302.510) allow for establishment of alternative DO criteria using the same provisions included in F.A.C. 62-302.800. Approval of alternative criteria requires a demonstration by the applicant that the water quality conditions are a result of natural or man-induced conditions that cannot be controlled or abated.

F.A.C. Chapter 62-4.244 describes the conditions under which a mixing zone may be requested, the criteria used by FDEP to evaluate requests for mixing zones, and the limitations that apply to mixing zones. No mixing zone or combination of mixing zones is allowed to significantly impact the designated uses of the receiving body of water. A separate mixing zone must be defined for each parameter, and a mixing zone cannot include a nursery area for aquatic biota. Mixing zone dimensions are determined by modeling, using anticipated concentrations of the specific parameter in the receiving water body.

D. IN-LAKE WATER QUALITY ISSUES

Beginning in 1973, water quality data have been collected on a regular (monthly or more often) basis at eight open-water monitoring stations. Since 1986, a total of 30 stations have been sampled. As a result, there is a detailed long-term record for open-water concentrations of phosphorus, nitrogen, chlorophyll *a*, and other water quality parameters. These data are routinely analyzed in order to assess long-term trends in the lake's condition, and the most recent evaluation of in-lake total phosphorus and chlorophyll *a* are shown in Figure 8. The recent upturn in phosphorus concentration is the result the complex internal processes, most notable being sediment resuspension.

Water quality in the lake has been substantially impacted by human activities occurring in the watershed. Coincident with increases in beef cattle ranching, dairy farming, citrus production, and urban development, the overall quality of water in the lake has declined. Most noticeable was the nearly two-fold increase in lake-water total phosphorus that has occurred in the early 1980s (Havens *et al.* 1995a). It also has been discovered that the lake sediments have accumulated a massive pool of phosphorus, which now is preventing recovery of the ecosystem (Olila and Reddy 1993). In this section, four specific water quality issues are described: (1) historical trends in nutrient loads, nutrient concentrations, and chlorophyll *a*; (2) current status of the lake, in terms of seasonal and spatial patterns of nutrients and chlorophyll *a*; (3) the role of sediment-water interactions in controlling phosphorus and chlorophyll *a*; and (4) water quality status in terms of Class I drinking water standards. It is intended that in the near future, this water quality monitoring will be interfaced with a more holistic program of ecological monitoring, which will include biological, as well as physical/chemical elements.

D1. Historical Trends in Nutrients and Chlorophyll *a*

In a comprehensive study (Havens *et al.* 1995a), historical trends in nutrient loads, water budgets, and in-lake nutrient and chlorophyll *a* concentrations were examined for the 20-year period from 1973 to 1992. In general, the results indicate that the lake experienced accelerated eutrophication from 1973-1982, and then appeared to leveled off from 1983 to the present. Symptoms include: increased concentrations of lake water total phosphorus, reduced ratios of total and soluble nitrogen:phosphorus, increased dominance of blue-green algae (cyanobacteria), and more frequent surface algal blooms (Havens *et al.* 1995a). During the same period,

Figure 8. In-lake total phosphorus and chlorophyll *a* concentration. Data are 5-year rolling averages from 8 open-water stations (L001-L008). (Only 3 years are used for the early chlorophyll a data point).

there were documented increases in the rate of phosphorus accumulation in the lake sediments (Engstrom and Brezonik 1993).

D1a. Water and Nutrient Budgets

For the 20-year period from 1973 to 1992, phosphorus loading rates to the lake have averaged near 570 tons/year, while outputs from the system have averaged near 150 tons/year. Consequently, there has been a net accumulation of about 460 tons/year of phosphorus in the lake's sediments (Table 10). When the rate of external phosphorus loading is adjusted for water residence time and inflow volume, the lake is classified as eutrophic by the modified Vollenweider phosphorus model (Figure 9). The rate of phosphorus loading increased through the early 1980s, and thereafter displayed a significant decline, to about 60% of the peak value.

Nitrogen loading rates have averaged near 10,000 tons/year, with an output mass of about 2,800 tons/year. When adjusted for residence time and inflow volume, the lake is classified as eutrophic by the modified Vollenweider nitrogen model (Figure 10). In terms of historical trends, the rate of nitrogen loading increased significantly through the early 1980s, and then declined rapidly through the early 1990s, which is attributed to the decline in back pumping from the EAA-EPD (James *et al.* 1995a).

The mass-balance budget also shows that the lake acts as a sink for nitrogen, with approximately 75% of the nitrogen introduced into the lake being retained (Table 10). Much of this may be lost to the atmosphere as N_2 gas, from the process of denitrification. Denitrification may be very important to the overall nitrogen cycle of Lake Okeechobee. However, as is also the case for other bacterially-mediated transformations of nitrogen in Lake Okeechobee, it has not been directly measured, and represents an area for future study.

In terms of nitrogen inputs to the ecosystem, the importance of nitrogen fixation by blue-green algae may account for as much as 30% of the total nitrogen inputs to the system (Phlips and Ihnat 1995). This input is not presently counted in the overall nitrogen budget shown in Table 10. Since nitrogen is presently limiting the growth of algae over a large area of the lake, additional information about nitrogen dynamics is crucial to successful modeling of algal biomass responses to management actions (i.e., load reduction strategies). The ratio of total nitrogen to total phosphorus (TN:TP) in the inflow water declined by approximately 10% during the period of record (Smith *et al.* 1995) and may have contributed to the coincident decline of lake water TN:TP ratios. This in turn may contribute to an increase in nitrogen-fixing blue-green algae in the system. This topic is considered in more detail in Chapter 4.

There also is evidence that a change in the interaction between sediments and water column occurred, in terms of phosphorus dynamics, during the 1973 to 1992 period. Lake water calcium levels, which strongly regulate the rate of phosphorus

Table 10. Hydrologic and nutrient budget information for Lake Okeechobee; averages for the period 1973 to 1992 (from James *et al.* 1995a).

Parameter	Average Value	Units
Water residence time	3.4	years
Inflow volume	2.4	km^3/year
Rainfall volume	1.5	km^3/year
Outflow volume	1.4	km^3/year
Evaporation	2.5	km^3/year
Phosphorus input	570	tons/year
Phosphorus output	151	tons/year
Water column change	-42	tons/year
Net sink	461	tons/year
Nitrogen input	10,064	tons/year
Nitrogen output	2,838	tons/year
Water column change	-337	tons/year
Net sink	7,563	tons/year

deposition to the sediments (Olila and Reddy 1994), declined, as did relative phosphorus sedimentation rates. This suggests that the lake sediments are declining in their ability to assimilate incoming phosphorus, although the capacity for this assimilation remains very high (Reddy *et al.* 1993).

D1b. Lakewater Nutrient Concentrations

Water total phosphorus concentrations have displayed a dramatic pattern of historical change (James *et al.* 1995b). As external loading increased in the 1970s, lakewater total phosphorus concentrations doubled, from near 50 to over 100 μg/L (Figure 11). However, when external loads declined through the 1990s, there was no significant change in lake water total phosphorus, which now averages 90 μg/liter. This lack of response by the in-lake phosphorus concentration to load reductions reflects the high rate of internal phosphorus loading from the lake sediments.

In contrast to the lack of correlation with external loads, lake-wide total phosphorus concentrations are strongly correlated with water levels (Canfield and Hoyer 1988) and wind (Maceina and Soballe 1991). Several mechanisms have been

Figure 9. Vollenweider model phosphorus output. Phosphorus loading rates (Lp) adjusted for water residence time (Tw) and inflow volumes (qs), in relation to critical values derived from the modified Vollenweider model, which classifies lakes as eutrophic, mesotrophic, or oligotrophic (Federico *et al.* 1981).

Figure 10. Vollenweider model nitrogen output. Nitrogen loading rates (Ln) adjusted for water residence time (Tw) and inflow volume (qw), in relation to critical values derived from the modified Vollenweider model, which classifies lakes as eutrophic, mesotrophic, or oligotrophic (Federico *et al.* 1981).

Figure 11. Historical nutrient trends. The concentrations of total nitrogen (TN), total phosphorus (TP), the TN:TP ratios, dissolved inorganic nitrogen (DIN), soluble reactive phosphorus (SRP), and DIN:SRP ratios in the water column of Lake Okeechobee. Solid bar denotes the pre-IAP period, when backpumping was frequent.

proposed to explain the relationship, including: flooding of marsh vegetation and subsequent phosphorus release from dying plants; and enhanced water column stability when water levels are high, leading to low oxygen conditions and subsequent soluble phosphorus release from sediments. Considerable research was directed at the marsh flooding process in the late 1980s, and the general conclusion was that the marsh zone generally is hydrologically uncoupled from the limnetic zone, but when water exchange does occur, the marsh zone is a strong sink for phosphorus (Sheng & Lee 1991, Dierberg 1992, Harris *et al.* 1995). In contrast, there has been no research to quantify how water levels affect dissolved oxygen profiles or soluble phosphorus release. In fact, there are few data regarding oxygen profiles in the lake under any conditions. Research efforts began in the summer of 1996 to fill this information gap, and ultimately, SFWMD staff will quantify soluble phosphorus release rates under different water depth scenarios.

Total nitrogen concentrations more closely followed the pattern of external inputs. Between 1973 and 1980, the external loading rate of nitrogen increased slightly, and the concentration of nitrogen in the inflowing water increased significantly (James *et al.* 1995b). At the same time, the lake water concentrations of total nitrogen increased from 1,500 to 3,000 µg/L (Figure 11). When external loads were significantly reduced after 1980 (as a result of agricultural BMPs and a reduction of backpumping from the EAA due to the IAP) lake water total nitrogen concentrations returned to the 1,500 µg/L level. Because total nitrogen declined while total phosphorus did not, the lake water TN:TP ratios declined from near 40:1 in the 1970s to about 20:1 in the early 1990s. The ratio of soluble N:P (soluble nutrients are those readily available for uptake by algae) displayed a similar decline. According to Smith *et al.* (1995) the lower ratios of TN:TP and soluble N:P have made the water column of Lake Okeechobee more favorable for the proliferation of nitrogen-fixing blue-green algae.

Despite the documented importance of water quality to the composition of wetland communities (Havens and Steinman 1995), there is not a historical record of marsh zone water quality in Lake Okeechobee. To fill this information gap, a set of ten monitoring stations were selected and monthly sampling of marsh zone water quality was initiated in 1996. Sampling of an inner marsh site in the southwestern portion of the lake indicates that this region has very low phosphorus concentrations relative to the open water region of the lake. This suggests there may be interesting ecological parallels between the inner marsh zone of Lake Okeechobee and pristine areas of the Everglades. In addition, a collaborative study has been initiated with Archbold Biological Station investigating the phosphorus kinetics and fluxes between the biotic communities in the marsh zone.

D1c. Chlorophyll *a* Concentrations

Concentrations of chlorophyll *a*, which serve as an indicator of phytoplankton biomass in lake water, display a historical trend that do not correspond, in any simple manner, with the trends in nutrient loads or in-lake concentrations. From 1973 to 1980, while external nutrient loads and lake water nutrient concentrations were increasing, chlorophyll *a* did not display any significant upward or downward trend. However, from 1980 to 1992, while nitrogen concentrations declined and phosphorus concentrations remained high but stable, chlorophyll *a* increased significantly, from approximately 20 to 30 μg/L. Havens (1995) studied this phenomenon, and proposed four explanations that could be tested in future research and/or modeling efforts: (a) phytoplankton growth was stimulated by the 3° C rise in water temperatures that occurred during the 12-year period; (b) growth was stimulated by greater underwater light penetration, which occurred due to the 15% decline in average wind velocities (wind resuspends bottom sediments, which reduces light penetration) during the 12-year period; (c) the 50% decline in TN:TP and soluble N:P ratios favored dominance by nitrogen-fixing blue-green algae, and many of these species have the ability to float and may be sampled more readily-corresponding to an increase in surface chlorophyll *a* concentrations; and (d) a greater dominance by large filaments of blue-green algae has led to less grazing impacts on the algal biomass by zooplankton. Regardless of the cause, it appears that excessive nutrient loading (in the 1970s and early 1980s) has established conditions favorable for phytoplankton growth - so that the ultimate growth rates are now a function of less-predictable meteorological or biological factors. This situation has been observed in other nutrient-stressed lakes (Gophen 1994).

There is also evidence that lake stage affects chlorophyll *a* concentrations, but only in certain areas of the lake. Maceina (1993) demonstrated that in shallow marsh zone areas, along the western edge of the lake, there is a significant positive correlation between lake stage and yearly average chlorophyll *a*. Hanlon and Havens (1994) found that this relationship persisted even when inter-annual variation in external nutrient loading and wind velocity were factored out in a statistical analysis. Two explanations for the stage-chlorophyll relationship have been offered. Maceina (1993) proposed that at high stage, there is greater transport of inorganic phosphorus from mid-lake to the outer edge of the marsh zone; this phosphorus presumably would stimulate phytoplankton growth. Evidence in support of this hypothesis includes the discovery of a strong clockwise water circulation gyre in the lake (see below), and the fact that phytoplankton appear to be phosphorus-limited at sites close to the marsh edge (Walker and Havens 1995). Phlips *et al*. (1993) proposed that when stage is high, benthic (bottom-dwelling) plants and algae experience light limitation and die. In their absence, the phytoplankton grow more rapidly since they experience less competition for nutrients. Recent experimental research results (Havens *et al*. 1996c) lend support to the concept of competition between phytoplankton and benthic algae. Regardless of the mechanism, the stage-chlorophyll *a* relationship is a reality in the near-shore area.

D1d. Chlorophyll *a* as an Indicator of Algal Blooms

Lake water quality, for recreation, wildlife, or drinking, is likely to be affected more by extremes in chlorophyll *a* than by long-term or yearly means. The SFWMD staff have made efforts to quantify "blooms," defined as chlorophyll *a* concentrations that are considerably higher than the average, and which produce noticeably green water (Havens *et al.* 1995b). The criterion adopted, 40 µg/L, is also that used by the State of Florida to designate use-impairment. When we examine the frequency of water samples that exceed the 40 µg/L standard, it is evident that there has been a lake-wide increase in blooms since the early 1980s (Figure 12). Given the short time-frame, this is another strong indicator of accelerated lake eutrophication.

D2. Seasonal and Spatial Variation in Nutrients and Chlorophyll *a*

The current status of water quality in Lake Okeechobee, including detailed information on seasonal and spatial variability, was provided by the Lake Okeechobee Ecosystem Study (Aumen and Wetzel 1995). This 5-year (1988 to 1992) investigation was conducted by scientists of the University of Florida, and the FGFWFC, with project management and financial support provided by the SFWMD. Over 100 stations were sampled for water quality at semi-monthly intervals (Figure 13). The results indicate that considerable heterogeneity of water quality exists, in both time and space (Phlips *et al.* 1995a). During winter, much of the lake experiences poor light penetration, because winds resuspend mud sediments from the lake bottom. As a result, chlorophyll *a* concentrations are low, except in shallow marsh areas where there is hard sand, rock, and peat sediments (less prone to resuspension) that allow greater light penetration in the water column.

During summer, conditions are very different. Because wind velocities are lower, there tends to be less sediment resuspension, and nutrients generally limit algal growth. In particular, nitrogen limitation occurs, although both nitrogen and phosphorus may be limiting in outer edge of the marsh areas (Aldridge *et al.* 1995).

Based on the interrelations of total phosphorus, total nitrogen, chlorophyll *a*, and light availability, Phlips *et al.* (1995a) defined four open-water regions of the lake, hereafter referred to as ecological zones (Figure 14a). The *North* ecological zone is characterized by high concentrations of total phosphorus and chlorophyll *a*, and a predominance of nitrogen limitation of phytoplankton growth. This region is in the proximity of high phosphorus inputs from TCNS and the lower Kissimmee River. The *Center* ecological zone also has high total phosphorus concentrations, but experiences light limitation during much of the year (except mid-summer, when nitrogen is limiting) due to a greater water column depth. The *Edge* ecological zone has lower concentrations of phosphorus, greater light availability than other zones, and experiences severe nutrient limitation (nitrogen or nitrogen + phosphorus) year-round. This zone displays sporadic, but sometimes very high peaks in chlorophyll *a*, which unlike other areas of the lake, appears to be in response to pulses in external loads (Phlips *et al.* 1995b). The *Transition* ecological zone occurs between the edge and center, and displays intermediate characteristics.

Figure 12. Frequency of phytoplankton blooms in Lake Okeechobee. Blooms are defined as chlorophyll *a* concentrations that exceed 40 µg/L. A lake region enclosed by a 10% contour line in the figure has chlorophyll *a* levels above 40 µg/L on 10% of the dates when samples were collected.

Figure 13. Water Sampling locations. Semi-monthly water quality samples collected during the Lake Okeechobee Ecosystem Study, 1988 to 1992 (Phlips *et al.* 1995a).

Figure 14. The ecological zones of Lake Okeechobee (A), as defined in the text according to Phlips *et al*. (1995a); and (B) the composition of lake sediments, as determined by Olila and Reddy (1995).

Boundaries of the ecological zones correspond closely with the boundaries of different sediment types (Figure 14b) on the heterogeneous bottom of Lake Okeechobee, because sediment type (easily resuspended mud versus more consolidated sand, rock and peat) along with wind velocity largely determines water column conditions in the shallow lake.

The ecological zone concept is important to future research, modeling, monitoring and management. It is no longer appropriate to consider the lake as a homogeneous mixed system for any of these activities. Indeed, changes have already been made in the SFWMD research program to quantify phytoplankton responses to nutrients and grazing pressure - replicate studies are being conducted in each ecological zone. In the most recent development of the Water Quality Analysis Simulation Package (WASP5) water quality model, four open-water zones are included in the model (each with different relationships between chlorophyll *a* and environmental forcing functions). In biological monitoring of the lake, plankton, benthic animals, and periphyton are being sampled at sites in each zone, and in chemical monitoring, the SFWMD has added new stations in order to better represent the *Edge* zone in lake-wide sampling. From a management standpoint, it is important to recognize that each zone may respond differently to changes in external nutrient loading, alterations in regulation schedules, or other events. In particular, the *Edge* zone will likely be the first to display positive responses (lower phytoplankton biomass, and lower relative biomass of blue-green algae) to successful load reductions (Phlips *et al.* 1994) and it appears to be most sensitive to variations in lake stage.

D3. Sediment-Water Interactions and Internal Phosphorus Loading

Considerable research has been done to quantify the internal phosphorus dynamics of Lake Okeechobee, and to describe the general interactions between wind, water, and sediments. These results are contained in the multiple-volume report entitled Lake Okeechobee Phosphorus Dynamics Study (Reddy *et al.* 1995), and in several papers published in the peer-reviewed literature.

Major findings that relate to water quality (in terms of phosphorus concentrations) include:

(a) The rates of sediment deposition and phosphorus accumulation in the lake sediments have increased rapidly over the last 150 years. The most rapid increases occurred in the last 40 to 50 years.

(b) The lake sediments now contain over 30,000 tons of phosphorus, and in some areas consist of a mud layer nearly 1 meter thick (Figure 15). The storage of phosphorus in surface sediments is 55% greater than the yearly phosphorus load to the lake.

Figure 15. The thickness (cm) of mud sediments in Lake Okeechobee (Kirby *et al.* 1994).

(c) The mud sediments appear to be of recent origin - the lake may have been largely sand-bottomed 200 years ago.

(d) Wind and waves cause the resuspension of hundreds of tons per day of sediments into the water column.

(e) Along with diffusive fluxes, this physical resuspension is responsible for high internal phosphorus loading. Loading rates vary with sediment type, ranging from 0.7 mgP/m^2/day for mud, to 1.1 mgP/m^2/day for marsh sediments.

Overall, the internal loading rate is estimated to be equal to the external loading rate, on a yearly basis. However, this is gross loading; the net movement of phosphorus is from lake water to sediments, as indicated by the nutrient budget results presented in section 1a.

Given the role of sediment-water interactions to the recovery of Lake Okeechobee from phosphorus overloading, it will be important to periodically assess sediment parameters including: phosphorus accumulation rates, sediment depths, equilibrium phosphorus concentrations (which determine whether soluble phosphorus transported into the water column will remain in solution or move back into a particulate phase), and internal mass and loading rates.

The flow of lake currents is caused by wind, which may vary with wind velocity, direction, and water depth, but generally forms distinct surface and bottom patterns (Figure 16). As mentioned above, this may be an important factor affecting phytoplankton dynamics.

Better information regarding selected aspects of in-lake phosphorus cycling and all aspects of the nitrogen cycle is required as input to the SFWMD's water quality model for Lake Okeechobee (WASP). This model may be one of the best tools for predicting how the lake will respond to changes in watershed and lake management, especially from the standpoint of external nutrient load reductions and water level regulation changes. At present, the predictive capabilities of the model are weak because sufficient data for calibration and verification are lacking.

SFWMD staff have identified several areas of information that are critical for model enhancement: (1) information on the phosphorus content and spatial distribution of fluid mud, which overlies the more consolidated sediments at the lake bottom; (2) information on rates of phosphorus mineralization following death of plankton and other living organisms in the water column; (3) information on rates of soluble phosphorus release from mud sediments, and how that release is affected by season and water level; (4) information on how water depth affects submerged plants, and how those plants in turn affect the wind-driven resuspension of sediments and their associated nutrients into the water column; and (5) information on all aspects of

Figure 16. Modeled water circulation patterns in Lake Okeechobee. Circulation gyres of surface and bottom water on 6/14/89 are illustrated.

the nitrogen cycle. As indicated, nitrogen limits algal growth and bloom-formation on nearly a lake-wide basis, yet nitrogen dynamics have been all but ignored in past research efforts. It is also critical that the WASP water quality model be interfaced with a lake hydrodynamic model, since wind-driven water currents may dramatically affect the spatial distribution of nutrients and algal blooms in the lake. This effort is now underway by SFWMD staff.

D4. Class I and III Lake Water Quality Parameters

In regard to in-lake conditions, the CH2MHILL report (1995) consisted of an evaluation of the SFWMD's water quality and biological monitoring data, collected at nine open-water stations during the period 1972-1991 (Figure 17). Because Lake Okeechobee is classified as a drinking water source in Chapter 17-302, F.A.C., in-lake conditions were compared to Class I standards. Both the frequency and magnitude of exceedences of the numerical standards were considered.

Results of the study indicate that Class I criteria for the following parameters were exceeded at in-lake stations: alkalinity, dissolved oxygen, pH, turbidity, un-ionized ammonia, iron, cadmium, lead, zinc, and mercury (Table 11). The exceedences are caused by a variety of mechanisms, most of which are natural. The following summarizes the conclusions of CH2MHILL regarding the nine exceeded standards.

Alkalinity. The Class I criterion for alkalinity requires a minimum value of 20 mg/L $CaCO_3$. Out of nearly 274 to 300 total observations per station, only 1 to 3 per station were less than the minimum.

Dissolved Oxygen. The Class I criterion for dissolved oxygen requires a minimum value of 5 mg/L. The in-lake stations had between 118 and 263 measurements for this parameter. Only four stations had measurements (one each) below the minimum. These low values were probably caused by decomposition of algae and plants.

pH. The Class I criteria for pH include minimum (6.0) and maximum (8.5) values. The in-lake stations had between 100 and 200 observations for this parameter. The range of exceedence at the stations was from 5 to 35%. Most of the exceedences were values above the maximum criterion of 8.5, and were likely caused by algal photosynthesis.

Turbidity. The Class I criterion for turbidity requires a maximum value of 41.4 NTUs. All but one of the in-lake stations showed turbidity exceedences. These exceedences are related to the shallow nature of the lake, and wind-driven resuspension of mud bottom sediments described above.

Un-ionized Ammonia. The Class I criterion for un-ionized ammonia is 0.02 mg/L. For the in-lake stations, there were between 100 and 200 total observations; only 1 to

Figure 17. Water quality sampling locations. The open-water monitoring stations (open circles) from which 1972-1991 data were considered for exceedences of Class I water quality standards (CH2MHILL 1995).

Table 11. Exeedences of Class I criteria at in-lake stations.

5 observations per station displayed exceedences. This is considerably lower than the frequency of exceedences observed in inflow water. The ability of algae and bacteria to utilize ammonia as a nitrogen source appears to minimize the potential for un-ionized ammonia exceedences in the lake.

Iron. The Class I criterion for iron (0.3 mg/L) is designed to prevent discoloration and staining by domestic water supplies. All of the in-lake stations had exceedences of this criterion, with a range of 30 to 75% of observations. Iron was the most notable parameter with exceedences that could affect drinking water quality, perhaps causing objectionable taste, and staining of dishes and clothes. The widespread distribution of high iron concentrations in the lake (and inflows) indicates that this is a natural condition. The most likely source is local soils.

Cadmium, Lead, and Zinc. The Class I criteria for cadmium (Cd), lead (Pb), and zinc (Zn) are calculated as a function of water hardness, and therefore do not have specific values. Very few observations have been made for these three parameters (generally less than 20 per station for the entire 20 year period), and exceedences were rare. Three in-lake stations displayed 1 to 2 exceedences for Cd; one in-lake station displayed a single exceedence for Pb; and three in-lake stations displayed a single exceedence for Zn.

Mercury. The number of observations for Hg was also very low - four to ten per station. Nearly all data for in-lake stations was reported as "not detected." Since the minimal detection limit for Hg analysis was below the Class I criterion of 0.012 μg/L, no meaningful evaluation of compliance is possible.

Other aspects of water quality, including pesticides, PCBs, biological integrity, and total coliforms, were not measured at the in-lake stations, and as such, represent an area where information is needed. It also is important that compliance with Class I criteria be assessed using more contemporary (post 1994) data, since conditions in the lake may change from year to year.

The WASP water quality model and Lake Okeechobee hydrodynamic model can be used to estimate how concentrations of Class I parameters, in addition to nutrient parameters, are likely to respond to management actions, such as changes in lake stage.